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THE NATURE OF ORE DEPOSITS

BY

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TRANSLATED AND REVISED

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TRANSLATOR'S PREFACE.

In presenting an English edition of Professor Beck's 'Lehre von den Erzlagerstatten,' for which he has generously given his consent, a few words of explanation are necessary. I was originally asked by the publishers to practically rewrite the book from an American standpoint, giving greater prominence to American ore deposits. This was abandoned because it involved serious abridgement of the descriptions of important foreign localities, descriptions which make the work especially valuable to American engineers and geologists. I have, however, in most instances, consulted the original authorities, and written many new descriptions of American ore deposits, especially where, by reason of personal study or of recent detailed scientific investigation made since Professor Beck's book was issued, such a course seemed advisable. For such additions and changes I alone am responsible.

A slight abridgment of the historical matter will also be noted. In the rendering of technical terms the word 'formation' has been used only exceptionally, as it is not in accordance with current American usage in treating on ore deposits on account of its use in general geology. Fläche, Stehende, etc., have been dropped in the translation. Lode and vein have been discriminated, as done by Emmons. The arrangement has not been altered, although it is recognized that it is not so convenient for reference as it would be to group the descriptions under the name of the predominant metal. The table of contents and index will, however, fully answer the requirements of those who only seek special information about a particular metal.

I am under deep obligation to Mr. Robert Stein, of the Bureau of Statistics, for his help in the translation, and to Mr. S. F. Emmons for his criticism and revision of a number of descriptions. The prefaces are given in the original German, that the charm and spirit of Professor Beck's text may be retained.

WALTER HARVEY WEED.

Washington, D. C., July 26, 1905.

AUS DEM VORWORT ZUR ERSTEN AUFLAGE.

Als die Vorträge über Lagerstättenlehre an der Königlichen Bergakademie zu Freiberg mir übertragen worden waren, wurde ich gar bald inne, wie sehr Lehrer sowohl wie Schüler dieser Wissenschaft ein dem heutigen Stande derselben entsprechendes Lehrbuch in deutscher Sprache vermissen. Hieraus entsprang der Plan, selbst jene Lücke auszufüllen, und alle Studien und Reisen, alle Niederschriften, Auszüge und Erkundigungen wurden fortan mit diesem Ziele vor Augen ausgeführt. Zugleich bot die umfassende, von A. W. Stelzner so gründlich durchgearbeitete und nach seinem Tode stark vermehrte und von neuem durchgesehene Lagerstättensammlung der Bergakademie eine vortreffliche Grundlage, auf der allmählich das Werk aufgebaut werden konnte.

Durch viele Reisen und Grubenbefahrungen versuchte der Verfasser von allen zu beschreibenden Lagerstättentypen eigene Anschauung zu gewinnen. Dankbar war er sich hierbei der steten Anregung und Förderung bewusst, die der Wohnsitz und die amtliche Thätigkeit in der alten Bergstadt, der ununterbrochene Verkehr mit befreundeten Collegen aus den wissenschaftlichen Nachbargebieten und die vielen Berührungen mit erfahrenen Männern der Praxis gewähren mussten. Auch die engen Verbindungen mit ausländischen Bergrevieren durch alte Freiberger Bergingenieure, die kommen und gehen und selten mit leeren Händen kommen, waren einer solchen Arbeit höchst förderlich. Ebenso dankbar wurde die Schulung im praktischen geologischen Arbeiten empfunden, die der Verfasser als die Frucht einer zwölfjährigen Dienstzeit an der Kgl. sächsischen geologischen Landesanstalt unter dem von ihm hoch verehrten Herrn Geheimen Bergrath Prof. Dr. H. Credner in das neue Amt mitbringen durfte.

Seit B. v. Cotta's Lagerstättenlehre erschien, ist der zu bewältigende Stoff ganz riesenhaft angeschwollen. Man denke nur allein an die seither zugewachsene, damals nur erst in ihren Anfängen vorhandene, jetzt so überaus grossartige und werthvolle amerikanische Litteratur auf diesem Gebiete. Eine Unzahl von Veröffentlichungen musste eingesehen und verarbeitet, ihr Inhalt mit den Belegstücken der Sammlung verglichen werden. Wer den Umfang der Lagerstättenlitteratur nur einigermassen kennt, wird es entschuldigen und erklärlich finden, wenn dies und jenes trotz allen guten Willens vergessen werden konnte. Für alle freundlichen Belehrungen, die künftige Verbesserungen ermöglichen, besonders auch für Uebersendung von Publicationen werde ich stets dankbar sein. Eine Lück-

enhaftigkeit wird man namentlich bei den statistischen Notizen finden, die in diesem Werke den Zweck haben, eine Vorstellung von der Grösse der Erzlagerstätten und daneben auch von deren ökonomischer Bedeutung zu erleichtern.

Zu grossem Danke verpflichtet bin ich Allen, die mich durch Beantwortung von Fragen, durch Sendungen von Litteratur und Belegstücken, durch Ueberlassung von Notizen und Skizzen in so uneigennütziger Weise unterstützt haben, ganz besonders auch meinem Collegen, Herrn Professor Uhlich, der mir den Abschnitt über die markscheiderische Ausrichtung von Verwerfungen lieferte, Herrn Bergingenieur H. Oehmichen, der mir bie der Ausarbeitung des Abschnittes über die Siebenbürgischen und Banater Lagerstätten behülflich war, und Herrn Privatdocent Bauinspector Hoyer in Hannover für eine Ausarbeitung über die Eisenerze der Gegend von Ilsede und Salzgitter. Dem Herrn Verleger endlich verdanke ich das opferwilligste Entgegenkommen bei der Ausstattung des Buches.

So wünsche ich denn dieser Arbeit eine nachsichtige Beurtheilung und gebe sie hinaus mit einem hoffnungsreichen

Glückauf!

Freiberg, im Juni 1900.

DR. RICHARD BECK.

VORWORT ZUR ZWEITEN AUFLAGE.

Dass es schon nach drei Jahren möglich und nothwendig war, eine zweite Auflage dieses Werkes hinaus zu senden, die zugleich mit einer französischen Uebersetzung (im Verlag von Béranger, Paris) erscheint, hat den Verfasser mit Freude erfüllt. Er war sich aber auch der grossen Verantwortlichkeit bewusst, die ihm hierbei auferlegt war, und ist ernstlich bestrebt gewesen, den Inhalt eines Buches, das vielfach als Lehrbuch dient, einer kritischen Nachprüfung zu unterwerfen. Auch bemühte er sich möglichst alle seit der ersten Auflage erschienenen wichtigeren Veröffentlichungen auf dem weiten Gebiete der Erzlagerstättenforschung zu berücksichtigen.

Die Anordnung des Stoffes musste mehrfach in Folge besserer Erkenntniss der genetischen Vorgänge abgeändert werden. Auch stilistisch wurde an vielen Stellen nachgefeilt. Mehrere Abbildungen wurden verbessert oder durch andere ersetzt. Eine grosse Zahl neuer Beispiele in zum Theil ausführlicherer Schilderung kamen hinzu.

Inzwischen vermochte der Verfasser seine Reisen zu eigenen Studien fortzusetzen und in dem Werke zu verwerthen. Er sah die wichtigsten Erzreviere auf Elba und in Toskana und schloss die monographische Bearbeitung mehrerer sächsischer Lagerstätten ab. Endlich konnte er viele seither eingegangene, reiche und interessante Zusendungen von Belegstücken aus auswärtigen Grubendistricten, die er grössten Theils alten Freibergern verdankt, in der zweiten Auflage berücksichtigen.

Die Litteratur ist seit 1900 wieder gewaltig angeschwollen. Mit grosser Freude gedenkt hierbei der Verfasser auch einer Anzahl von Veröffentlichungen seiner ehemaligen Schüler. Die Publicationen, die ihm in dankenswerther Weise von Seiten der Fachgenossen zugingen, waren so zahlreich und vielfach so inhaltsreich, dass die Zeit kaum hinreichte, um dies weitschichtige Material zu bewältigen.

Um den Umfang des Buches trotz der starken Erweiterung seines Inhaltes nicht zu vergrössern, musste theilweise kleiner Druck in Anwendung kommen.

Aufrichtigen Dank stattet der Verfasser allen denen ab, die ihn durch ergänzende Mittheilungen und durch Angabe einer Anzahl von Irrthümern innerhalb der ersten Auflage zu unterstützen die Güte hatten.

Freiberg, im Mai 1903.

DR. RICHARD BECK.

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INTRODUCTION.

DEFINITION OF AN ORE AND OF AN ORE DEPOSIT.

In a mineralogical sense an ore is a metalliferous mineral or a mixture of such minerals. Practically, however, this definition of an ore must be qualified by the statement that only those minerals and mixtures of minerals are ores *from which metals or metallic compounds may be produced on a commercial scale and at a profit.*

Two examples of equal mineralogic or petrographic value may differ materially: a basalt carrying enough magnetite to influence the magnetic needle, but yet containing less than 10 per cent of iron, is far from being an iron ore. On the contrary, a vein with a silver content of only 0.5 per cent is an ore deposit, since with this content it is commercially valuable. In the case of a gold deposit the amount sufficient to distinguish a gold ore from barren rock may be even less, for in California and Dakota gold ores with only from 4 to 6 grains per ton[1] of gold are exploited. Hence it is the economic point of view that must always be borne in mind, the profit of working being subject to variation in the course of time. While nickel and cobalt were formerly nicknames for materials which were thrown upon mine dumps as useless, and were considered as a mere nuisance in silver mining, today the compounds of these metals and the associated minerals are in great demand as ores.

To a certain degree a mineralized material may be an ore in one locality and yet not be an ore in another place, the cost of reduction depending on the proximity to lines of traffic and cheap freights.

The science of ore deposits is, in other words, the study and consideration of the deposition, distribution and origin of rock bodies containing ores in such quantities that they may be extracted profitably by mining operations.

The science of ore deposits is a branch of geology which can only be understood and practiced by those who have some knowledge of that science, particularly of petrography, and of course, also, a knowledge of mineralogy and chemistry.

[1]The ton as used in this work is the metric ton of 2,205 lb.

The Most Important Treatises on Ore Deposits, and the List of Journals in Which Ore Deposits Are Described or Discussed.

Bernhard von Cotta. 'Die Lehre von den Erzlagerstätten.' Two parts: First part, second edition; second part exhausted. Freiberg, 1859–1861. (Translated into English by F. Prime, New York, 1870.) Antiquated in many respects.

Albrecht von Groddeck. 'Die Lehre von den Lagerstätten der Erze.' Leipzig, 1879. (Translated into French by M. Küss.) Out of print and in many respects antiquated.

E. Fuchs and L. De Launay. 'Traité des Gîtes Minéraux et Métallifères.' Volumes I and II. Paris, 1893. Large encyclopedic handbook.

L. De Launay. 'Formation des Gîtes Métallifères.' Paris, 1893. Encyclopædia Scientifique des Aide Mémoires. Small manual.

J. A. Phillips and H. Louis. 'A Treatise on Ore Deposits.' Second edition. London, 1896.

J. F. Kemp. 'The Ore Deposits of the United States and Canada.' Third edition. New York and London, 1900.

Branner, J. C. 'Syllabus of Economic Geology.' Stanford University, California.

B. Lotti. 'I Depositi de i Minerali Metalli.' Milan, 1903.

Posepny, Van Hise, Emmons, Weed, Le Conte, Lindgren. 'Genesis of Ore Deposits.' Am. Inst. Min. Eng. New York, 1900.

Rickard, Weed and others. 'Ore Deposits—a Discussion,' New York, 1903.

The Engineering and Mining Journal, New York City.

Zeitschrift für Praktische Geologie. Edited by M. Krahman. Berlin.

Zeitschrift für das Berg-, Hütten- und Salinen-Wesen im Preussichen Staate. Published by the Minister for Commerce and Industry, Berlin.

Oesterreichische Zeitschrift für Berg- und Hüttenwesen. Vienna.

Jahrbuch der k. k. österreichischen Bergakademien. Vienna.

Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, Freiberg.

Berg- und Huttenmännische Zeitung. Published by G. Köhler (Clausthal) and F. Kolbeck (Freiberg). Leipzig.

Mining Journal. London.

Transactions of the Institution of Mining Engineers. Newcastle, England.

Transactions of the American Institute of Mining Engineers. New York.

Annales des Mines. Paris.

Geologiska Föreningens i Stockholm Förhandlingar. Stockholm.

Bergjournal. St. Petersburg. (In Russian.)

Revista minera periodico cientifico é industrial. Madrid.

Among general textbooks of geology which devote special attention to ore deposits we may mention: H. Credner, 'Elemente der Geologie,' ninth edition, Leipzig, 1903; M. Neumayr, 'Erdgeschichte,' second edition, Leipzig, 1900.

Many essays on ore deposits are also scattered through periodicals dealing with general geology, especially *Zeitschrift* der Deutschen geologischen Gesellschaft, Berlin; *Journal of Geology*, Chicago University, Chicago, Illinois; *American Journal of Science*, New Haven, Connecticut; *American Geologist*, Minneapolis, Minnesota; *Neues Jahrbuch* für Mineralogie, Geologie and Paleontologie, Stuttgart; and Tschermak's Mineralog u. Petrographische, Mittheilungun, Vienna.

The statistical data on the different mining districts of the world are best summarized in the following works, which appear every year: 'The Mineral Industry,' published by *The Engineering and Mining Journal*, New York and London; 'Mineral Resources,' published by the U. S. Geological Survey, Washington, D. C.

Classification of Ore Deposits.

A historical sketch of the different attempts at a classification of ore deposits has been given by J. F. Kemp[1], to which little need be added.

[1] J. F. Kemp. 'The Classification of Ore Deposits.' A review and a proposed scheme based on origin. Contributions from the geological department of Columbia College, No. 5. New York.

The practical miner even nowadays names and classifies his deposits according to their form and appearance, and this was the method used by the first scientific writers. Waldauf von Waldtenstein[1] (1824), and B. von Cotta[2] (1859), subsequently Lottner-Serlo[3] (1869).

G. Köhler[4] (1884) and lately H. Hofer[5] (1897) based their groupings solely on form. J. D. Whitney[6] (1854), J. Grimm[7] (1869), J. S. Newberry (1880), and J. A. Phillips[8] (1884), laid stress on the mode of origin. A. von Groddeck[9] (1879) on the other hand, introduced a mainly genetic system, and advocated this principle again in his essay of 1885[10].

Genetic principles were followed by H. S. Munroe, J. F. Kemp[11], F. Posepny[12], G. Gürich[13] and W. H. Weed[14].

A. W. Stelzner's system, used in his lectures, briefly stated in the program of the Freiberg Mining Academy and employed by him in arranging the collection of ore deposits in that institution, is also purely genetic. Finally, J. H. L. Vogt, among the more recent writers, furnished many important data for a scientific classification in this field, especially in his essay of 1894[15]. The classification of W. H. Weed follows a logical sequence from magmatic segregations to placer gravels, and utilizes the results of modern petrologic research and chemistry to a greater extent than preceding schemes. It entirely abandons form as a factor of importance and is thus purely genetic. Following Stelzner's system in many ways we have in the present work used the following classification:

[1] J. Waldauf von Waldenstein: 'Die besonderen Lagerstätten der nutzbaren Mineralien.' Volumes I and II. Vienna, 1824.

[2] B. von Cotta: 'Lehre von den Erzlagerstätten.' Volumes I and II. Freiberg, 1859.

[3] E. H. Lottner and A. Serlo: 'Leitfaden zur Bergbaukunde.' Volumes II and III. Berlin, 1869-1872.

[4] G. Köhler: 'Lehrbuch der Bergbaukunde.' Leipzig, 1884.

[5] H. Höfer: *Zeit.* f. Prak. Geol., 1897.

[6] J. D. Whitney: 'The Metallic Wealth of the United States.' Philadelphia, 1854.

[7] J. Grimm: 'Die Lagerstätten der nutzbaren Mineralien.' Prague, 1869.

[8] J. A. Phillips: 'A Treatise on Ore Deposits.' First edition. London, 1884.

[9] A. von Groddeck: 'Die Lehre von den Lagerstätten der Erze.' Leipzig, 1869.

[10] 'Bemerkungen zur Classification der Erzlagerstätten.' *B. u. H. Z.*, 1885,p.217.

[11] J. F. Kemp: 'The Ore Deposits of the United States.' New York, 1893.

[12] F. Posepny: 'Die Genesis der Erzlagerstätten.' *Jahrb.* d. k.k. osterr. Bergakademien. Vienna, 1895.

[13] G. Gürich: 'Ueber die Eintheilung der Erzlagerstätten.' Schlessche Ges. f. vaterl. Kultur. Breslau, 1899.

[14] 'Classification of Ore Deposits—a Proposal and a Discussion.' *The Engineering and Mining Journal*, Feb., 1903. Also 'Ore Deposits—a Discussion.'

[15] J. H. L. Vogt: 'Beiträge zur genetischen Classification.' 1894, p. 381.

CLASSIFICATION OF ORE DEPOSITS.

(COMPARE WITH TABLE OF CONTENTS OF THIS WORK.)

I. Primary Ore Deposits.

A. Syngenetic; formed simultaneously with the country rock.

1. *Magmatic segregations;* for example, magnetic iron ores in orthoclase porphyries.

2. *Sedimentary ores;* in part approximately in the same condition as at the time of their deposition, for example, bog iron ores; in part altered by metamorphic processes, as, for example, the magnetic iron ores of the crystalline schists.

B. Epigenetic deposits; formed later than the country rock.

1. *Veins;* fillings of fissures, together with kindred formations, for example, tin veins, in which filling of the fissures was accompanied by replacement of the wall rock.

2. *Epigenetic ore deposits other than veins.*

(a) Epigenetic deposits, formed essentially by an impregnation of non-calcareous rocks, the deposits being generally in distinct beds.

(b) Epigenetic stocks; formed essentially by a metasomatic replacement of calcareous rock, mostly in the form of stocks[1], pockets, or stringers; for example, the cadmium deposits in the Muschelkalk.

(c) Contact metamorphic ore deposits; ore-beds and stocks formed through contact metamorphism caused by Plutonic intrusive masses; for example, contact metamorphic magnetic iron ores.

(d) Ore-bearing cavity fillings; deposits formed essentially by a simple filling of pre-existing cavities mostly in the form of stocks or stringers; for example, pisolitic iron ores.

II. Secondary Deposits.

Those formed by the destruction and transposition of primary deposits:

1. *Residual deposits* formed essentially by chemical alteration of primary deposits.

2. *Placer deposits* formed essentially by mechanical degradation of primary deposits or placers.

[1] *i.e.*, irregular masses, with or without definite boundaries.

TABLE OF THE MOST IMPORTANT ORE MINERALS.

Ores.	Cryst. System.	Chemical Composition.	Percentage of	
			Gold.	Other Metals.
Gold				
Gold	isom.	Au, mostly (Au, Ag)		0.16—39 Ag
Krennerite	orth.	(Ag, Au) Te_2	35	
Nagyagite	"	$Au_2Sb_2Pb_{10}Te_6S_{15}$	5.9—7.6	57.2—60.5 Pb
Petzite	"	$(Ag, Au)_2Te$	3.3—25.6	40.8—59.6 Ag
Sylvanite	mono.	$Au\,Ag\,Te_4$	26.5—40.6	2.24—11.3 Ag
Calaverite	tri.	(Au, Ag) Te_2	39.5—	3.1 Ag

The following minerals are sometimes auriferous: pyrite, arsenopyrite, chalcopyrite, stibnite, zinc-blende.

Silver.			Silver.	
Argentite	isom.	Ag_2S	87.1	
Bromyrite	"	Ag Br	57.4	
Chlorargyrite	"	Ag Cl	75.2	
Embolite	"	Ag (Cl, Br)	61—69.8	
Dyskrasite	orth.	Ag_3Sb (?)	63.9—94.1	
Iodyrite	hex.	Ag I	45.9	
Polybasite	mono.	$Sb\,S_6\ (Ag, Cu)_9$	64—72	3—10 Cu
Proustite	hex.	$As\,S_3\,Ag_3$	65.5	
Pyrargyrite (dark ruby silver)	hex.	$3\,Ag_2S, Sb_2S_3$	59.8	
Silver, native	isom.	Ag	90—100	Often holding Sb, As, Hg, Co, Fe, Cu and Au
Stephanite	orth.	$5\,Ag_2S, Sb_2S_3$	68.4	
Stromeyerite	rh.	$Cu_2S + Ag_2S$	53.1	31.2 Cu

The minerals given in this table include only those of economic importance in mining and smelting or those which are particularly characteristic of certain deposits. The chemical formulas are chiefly taken from 'Tabellarischen Nebersicht der Mineralien' of P. Groth, 4th edition, 1898; revised in this edition to accord with Dana's Mineralogy.' The metallic percentages are from F. Kolbeck's new revision of Plattner's 'Blowpipe Analysis,' Leipzig, 1897.

The following minerals often hold silver: tetrahedrite, galena, zinc blende, pyrite, chalcopyrite, chalcocite:

Ores.	Cryst. System.	Chemical Composition.	Contents in Percentages of	
			Silver.	Other Metals.
Platinum.				
Platinum, native	isom.	Pt	70—90	Nearly always holds Fe, Cu, Rh, Ir, Pd and Os

Iridium, osmiridium, etc., also contain platinum.

Mercury.			Mercury.	
Cinnabar	hex.	Hg S	86.2	.....
Mercury, native	.....	Hg	.....	.....

Mercurial tetrahedrite also contains 1.56—1.73% quicksilver.

Lead.			Lead.	
Anglesite.	orth.	$PbSO_4$	68.3	
Boulangerite.	"	$2PbS+Sb_2S_3$	53.9—59.5	
Bournonite	orth.	$2PbS+Cu_2S+Sb_2S_3$	42.3	
Cerussite	"	$PbCO_3$	77.6	
Galena.	isom.	Pb S	86.6	
Jamesonite	orth.	$2PbS+Sb_2S_3$	50.6	
Mimetite	hex.	$3Pb_3As_2O_8+PbCl_2$	69.5	
Phosgenite	tetr.	$PbCl_2+PbCO_3$	73.8	
Pyromorphite.	hex.	$3Pb_3P_2O_8+PbCl_2$	76.2	
Wulfenite	tetr.	$PbMoO_4$	55.8	
Croicite	mono.	$PbCrO_4$	64.6	

Copper.			Copper.	
Atacamite.	orth.	$CuCl_2, 3CuO, 3H_2O$	52.7—59.4	
Azurite	mono.	$3CuO, 2CO_2+aq.$	55.2	
Bournonite.	orth.	$2PbS+Cu_2S+Sb_2S_3$	13.0	42.3 Pb
Bornite	isom.	$x Cu_2S + y CuS + 2FeS$	43—63.4	
Brochantite	orth.	$4CuO, SO_3+3aq.$	56.1	
Chalcopyrite (copper pyrite)	tetr.	$Cu_2S+Fe_2S_3$	34.5	

Ores.	Cryst. System.	Chemical Composition.	Contents in Percentages of	
			Copper.	Other Metals.
Copper.				
Chalcocite (cop'r glance)	orth.	Cu_2S	79.8	.....
Chrysocolla	.....	$Si\,O_3\,Cu.\,2\,H_2O$	33.9	.....
Covellite	hex.	$Cu\,S$	66.4	.....
Cuprite	isom.	Cu_2O	88.7	.....
Enargite	orth.	$As\,S_4\,Cu$	48.2	.....
Famatinite	"	$Sb\,S_4\,Cu$	43.2	.....
Tetrahedrite	isom.	$\left\{\begin{matrix} As_2S_7(Cu_7,\ Fe_2,\ Zn)_4 \\ Sb_2S_7(Cu_2,\ Ag_2,\ Fe,\ Zn)_4 \end{matrix}\right\}$	13—43	0—31 Ag 0.5—17.2 Hg
Copper, native	isom.	.....	.....	.....
Malachite	mono.	$CO_3\,[Cu.OH]_2$	57.4	.....
Tennantite	isom.	$As_2S_7(Cu_2)\,(Fe,\,Zn)_2$	47.7—51.6	.....

Pyrite and pyrrhotite are also cupriferous.

Nickel.			Nickel.	
Annabergite	mono.	$Ni_3\,As_2\,O_8 + 8$ aq.	29.2	.....
Chloanthite	isom.	$Ni\,As_2$	28.2	Contains Co.
Garnierite	.....	$Si\,O_4\,(Ni,\,Mg)\,H_2 +$ aq.	3—33	.....
Gersdorffite	isom.	$(Ni\ Fe)\ As\ S$	30—35.1	.....
Linnæite	"	$[(Ni,\,Co,\,Fe)S_2]_2(Ni,\,Co)$	14.6—42.6	11—40.7 Co.
Niccolite	hex.	$Ni\,As$	43.6	.....
Genthite	amor.	$Si_3\,O_{10}\,Ni_2\,H_4$	39.1	.....
Ullmannite	.....	$Ni\,Sb\,S$	27.6	.....

Pyrite and pyrrhotite are also nickeliferous.

Cobalt.			Cobalt.	
Asbolite	amor.	$Mn\,O_2,\,Co\,O,\,Cu\,O,\,H_2O$	19.4	.....
Erythrite	.....	$Co_3\,As_2O_8 + 8$ aq.	29.5	.....
Glaukodot	orth.	$(Fe,\,Co)\,(As,\,S)_2$	4.5—24.8	.....
Cobaltite	isom.	$(Co,\,Fe)\,As\,S$	35,5	.....
Linnæite	"	$[(Ni,\,Co,\,Fe)S_2]\,(Ni,\,Co)$	11—40.7	14.6—42.6 Ni
Skutterudite	"	$Co\,As_3$	20.8	.....
Smaltite	"	$(Co,\,Fe,\,Ni)\,(As\,S)_2$	8.2—23	.....

The following minerals also contain cobalt: pyrrhotite, white nickel pyrite, gray nickel pyrite, arsenopyrite, danaite, cobalt-arsenic-pyrite.

	Cryst. System.	Chemical Composition.	Percentage of Iron.	Percentage of Other Metals.
Iron Ores.				
Chamosite	.....	Fe O, Mg O, Al_2O_5, SiO_2, H_2O	33—47	
Hematite (red, specular iron)	hex.	Fe_2O_3	70	
Ilmenite (menacconite)	"	$FeTiO_2 + x\,Fe_3O_3$ x = 0—5	20.6—68	
Limonite	ortho.	$2\,Fe_2O_3 + 3\,H_2O$	59.9	
Magnetite	isom.	$FeO + Fe_2O_3$	72.4	
Titanite	"	$[(Fe\,Ti)O_2]_2Fe$	....	
Siderite	hex.	$FeCO_3$	48.2	
Mixed with other substances forms: Argillaceous sphärosiderite = iron carbonate + clay. Blackband = iron carbonate + coal. (Pisolitic ore bohnerz, minette) = oolitic limonite with clay and quartz Seerze = limonite, earthy; often oolitic.				
Iron Sulphides.				
Arsenopyrite	orth.	$FeS_2 + FeAs_2$	34.3	
Chalcopyrite	tetr.	$Cu_2S + Fe_2S_3$	30.5	
Pyrrhotite	hex.	Fe_nS_{n+1}	60—61.6	
Marcasite	orth.	FeS_2	46.6	
Pyrite	isom.	FeS_2	46.6	
Chromium Ores.			Chromium	
Chromite	isom.	(Fe, Mg, Cr) O + $(Cr_2, Al_2, Fe_2)O_3$	40—60 usually 40—53	15—25 Fe O
Manganese Ores.			Manganese	
Braunite	tetr.	Mn_2O_3	69.6	
Asbolite	.....	Mn O_2, Co O, Cu O, H_2O	c. 19	
Hausmannite	tetr.	Mn_3O_4	72.1	
Manganite	orth.	Mn_2O_3 + aq	62.5	
Polianite	orth.	Mn O_2	63.2	
Psilomelane	amor.	Combined with Mn O_2, Mn O, Ba O, K_2O and H_2O.	49.2—62.9	
Pyrolusite	orth.	Mn O_2	63.2	
Rhodochrosite	hex.	Mn C O_3	47.8	
Rhodonite	tric.	$[SiO_3]_2Mn_2$ commonly also $[SiO_3]_2(Mn\,Fe\,Ca\,Mg)_2$	42	
Wad	not cryst.	Predominant: Mn O_2 MnO and H_2O	.....	

	Cryst. System.	Chemical Composition.	Percentage of	
			Zinc.	Other Metals.
Zinc.				
Calamine	orth.	$Si\ O_3\ [Zn\ OH]_2$	53.7	.....
Hydrozincite	amor.	$Co_3\ [Zn\ OH]_2$	57.1	.....
Smithsonite	hex.	$Zn\ CO_6$	52.0	.....
Willemite	"	$Si\ O_4Zn_2$	58.1	.....
Wurtzite	orth.	Zn S	to 67	.....
Sphalerite	isom.	Zn S	67	The colored species up to 8% Fe S
Zincite	hex.	Zn O	80.2	.....
Bismuth.			Bismuth	
Bismutite	.....	$CO_3\ [Bi\ O]\ Bi\ (OH)_2$	87.1	.....
Eulytite	isom.	$[Si\ O_4]_3\ Bi_4$	83.8	.....
Bismuth, native	hex.	Bi	95—99.9	.....
Bismuthinite (bismuth glance)	isom.	Bi_2S_3	81.2	.....
Bismite (Bismuth ochre)	isom.	Bi_2O_3	89.6	.....
Tin.			Tin.	
Cassiterite (tinstone)	tetr.	$Sn\ O_2$	78.6	.....
Stannite (tin pyrite)	isom.	$Sn\ S_4\ Cu_2\ Fe$	24.1—31.6	23.6—29.8 Cu
Tungsten.			Tungsten.	
Scheelite	tetr.	$Ca\ WO_4$	63.9	.....
Wolframite	mono.	$WO_4(Mn, Fe)$	57.9—60.3	.....
Hubnerite	"	$Mn\ WO_4$	60.7	
Molybdenum.			Molybde'm	
Molybdenite	hex.	$Mo\ S_2$	59.0	.....
Antimony.			Antimony	
Stibnite (antimonite)	orth.	Sb_2S_3	71.7	.....
Cervantite	cryst.	$Sb\ O_4Sb$	79.2	.....
Stibiconite	.....	$H^2Sb_2O_5$	74.6	.....
Valentinite	orth.	Sb_2O_3	83.5	.....
Arsenic.			Arsenic	
Arsenic, native	hex.	As (Sb, Ni, Fe, Mn, S)	90—100	.....
Arsenopyrite	orth.	Fe As S	46	.....
Orpiment	"	As_2S_3	61.0	.....
Löllingite	"	$Fe\ As_2$	72.8	.....
Realgar	mono.	As_2S_2	70.1	.....

TABLE OF UNITS IN WHICH METALLIC CONTENTS OF ORES ARE MOST COMMONLY EXPRESSED.

In this work the metric ton of 2,205 pounds is used, unless otherwise stated.
100 kg. = 1 centner = 1 quintal.

GERMANY.

The contents are mostly given in percentages. In Saxony for silver ores "pound parts" are still in use. 1 pound part = 0.01 per cent or 100 grams per 1,000 kilograms.

The contents of gold ores are given in grams (g) per metric ton (t) of 1,000 kilograms. For statements of production the metric ton is used: 1 ton = 1,000 kilograms.

ENGLAND.

1 long ton = 2,240 lb. = 1,016 kg.
1 short ton = 2,000 lb. = 907.2 kg.
1 pound avoirdupois (lb.) = 453.6 g.
1 lb. = 16 ounces (oz.)
1 ounce (oz.) = 28.3 g.

The contents of gold and silver ores are entered by means of

1 ounce troy (oz.) = 31.1 g

1 pennyweight (dwt.) = 1–20 oz. = 1.5 gram.
1 grain (grn.) = 1–24 dwt. = 0.06 gram.
1 grain troy = 1 grain avoirdupois.

UNITED STATES.

Like England, except that the short ton is almost exclusively used, 1 ton 2,000 pounds = 907.2 kilograms.

1 kilogram (kg.) = 2.20462 pounds avoirdupois.
1 flask mercury = 76.5 pounds avoir. = 34.7 kg.

Gold contents in dollars:

1 dollar ($) = 100 cents (cts.).

1 oz. troy	= $20.6718		= $1.2929
1 dwt.	= $1.0386	for gold.	
1 grain	= $0.04306		for silver.
1 gram	= $0.6646		= 0.04157

IN MANY STATES OF SOUTH AMERICA.

Contents in marcos per cajon:

1 marco = 230 grams = 7.398 troy ounces.
1 cajon = 64 quintals.
1 quintal = 46 kg.

RUSSIA.

Gold contents are given in zolotniks per 100 poods or 10 berkowitz:

1 berkowitz = 10 poods	=	163.8 kg.
1 pood	=	16.379 kg.
1 zolotnik	=	4.265 g.
1 dole	=	0.044 g.

SECTION I.

MAGMATIC SEGREGATIONS.

It is known that all eruptive rocks, especially those with but little silica, in rising from the unknown depths of the earth's interior to higher regions of the crust or to the surface, bring with them metals and metallic compounds, mostly, it is true, in very small amount. Magnetite and titanic iron ore, also pyrite, magnetic pyrite and chromite, are found in the form of small grains and crystals, scattered rather uniformly through many such eruptive rocks, in which the nature, microscopic intergrowth and relation to other constituents show conclusively that these small ore particles are primary constituents of the rock. It is true, as a rule, that such examples do not form true ore deposits, since the amount of these primary ores contained in such rocks is too small to pay for mining. However, weathering and erosion occasionally lead to a concentration on the earth's surface of these uniformly disseminated metallic minerals, as will be explained in the section on placers.

In some cases a concentration of the ores either into stock-like masses or into bands (schlieren) has taken place in the rock either before or during its solidification from the molten condition; these magmatic segregations or secretions, being of primary origin, will be considered first in this work.

Although concentrated in compact masses, the ore of these magmatic deposits is exactly the same as that which occurs in sparsely scattered particles through the enclosing rock, in which the ore minerals are accessory constituents. This, as will be shown in specific cases, is proven by the conditions of microscopic structure and intergrowth. This particular fact is the most important argument for the truly primary nature of such deposits, and enables one to discriminate between magmatic segregations and those accumulations of ore that have been formed through secondary processes in an eruptive mass.

The exact physico-chemical processes involved in the segregation of definite components of the magma into distinct portions of different composition, the so-called process of magmatic differentiation, is not as yet understood, although this problem has, in recent decades, occupied the attention of many investigators.[1]

[1] A very comprehensive presentation of these relations was given by J. P. Iddings: 'The Origin of Igneous Rocks.' Phil. Soc. of Washington, *Bull.* XII, pp. 89-214,

As regards this particular theory of the origin of ore deposits, the work of J. H. L. Vogt is most important. The process had long been recognized in examples of lean ore; notably the remarkable "mixed lodes" described by H. Bücking and others, where, in an eruptive dike, the more basic material of the magma has become concentrated in the two borders in sharply defined zones, making three parallel lodes or dikes side by side. Attention has also been devoted for a good while to the more basic, and often more highly iron-bearing marginal facies of eruptive stocks and large massives. In this segregation, processes of diffusion seem to have played a leading part. Teall, Lagorio and Brögger long ago noted the experiments of Soret (1879-1881), who, upon an unequal heating of different parts of saline solutions, obtained a different distribution of the salts, the solutions becoming more concentrated in the colder part than in the warmer. This is a consequence of the principle subsequently developed by van t'Hoff that the osmotic pressure increases in proportion to the absolute temperature. No doubt, however, other causes not yet known co-operate in producing this result.

Following J. H. L. Vogt, we will use the following grouping of ore deposits formed by magmatic differentiation according to the character of the ores predominant in each case:

A. Segregations of native metals.

B. Segregations of oxidic ores.

C. Segregations of sulphide and arsenical ores.

(A) Segregations of Native Metals in Eruptive Rocks.

1. *Segregation of Native Iron in Basalts.*

The famous occurrence of native iron in the porphyritic feldspar basalt of Ovifak on Disko Island on the west coast of Greenland[1] is of great scientific, but of no economic importance.

Since the time of Captain Ross's visit it had been known that the Esquimaux worked up natural native iron into tools, but the place whence they obtained the raw material was not known. Finally A. E. Nordenskiold, in August, 1870, discovered the most important place to be Blaafjeld, on the

1892. Also in other publications. Compare also J. H. L. Vogt: 'Formation of Ore Deposits Through Processes of Differentiation in Basic Eruptive Magma.' *Zeit. f. Prak. Geol.*, 1893, p. 4, etc. The researches of J. Morozewitz are also of the greatest importance in this connection. 'Exper. Untersuch. über die Bild. d. Min. im Magma.' Tschermak's *Min. Mitth.*, 1899, Vol. XVIII, pp. 1-240.

[1] G. Nauckhoff: 'On the Occurrence of Native Iron in the Basalt Lode at Ovifak.' Tschermak: *Min. Mitth.*, 1874, pp. 109-136. J. K. V. Steenstrup: 'On the Iron of Greenland.' *Zeit.* d. Deutch. Geol. Gesell. 1876, pp. 225-233, and in the *Meddelelser fra Gronland* IV. Copenhagen, 1882. A. E. Törnebohm: 'On the Iron Bearing Rocks of Ovifak and Assuk.' Appendix to *K. Svenska Vet. Ak. Handl.*, Vol. V, No. 10, Stockholm, 1878, also contains further papers.

south side of Disko Island. In 1871 a special expedition, with G. Nauckhoff as geologist, undertook a detailed investigation of the locality, and carried to Europe not only several very large blocks of iron found lying loose on the shore, but also abundant material still enclosed in the rock. It is now generally believed that the basalt of Ovifak is not a dike, but forms a sheetlike flow such as is common in the Tertiary coal-bearing formation of that region. This basalt porphyry encloses, according to A. E. Törnebohm, masses of a doleritic rock belonging to an earlier period of formation, holding inclusions of a highly graphitic anorthite rock. This dolerite consists of labradorite, augite, olivine, titanic iron ore, magnetite and a glassy groundmass. Furthermore, it contains native iron (Schreibersite), usually near the boundary with the anorthite inclusions, also troilite, magnetic pyrite, graphite and a silicate, for the most part greatly altered and resembling hisingerite. The metallic iron appears in flakes, grains, globular masses and large lumps. On etching, it shows the Widmanstatten figures and contains nickel and cobalt, according to a new analysis by A. Iwanoff[1].

Fe	92.91
Ni	2.66
Co	0.69
Cu	0.19
C	3.29
S	0.26
	100.00

The rust-like decomposition crust of the ore consists essentially of basic hydroxides, basic oxychlorides and basic sulphates of iron. Many observers have noted, as shown in the illustration of thin sections of the rock given in Törnebohm's report, that in the smaller nests of iron the metal apparently must have been segregated after the other constituents. Nauckhoff and Törnebohm demonstrated that the iron probably occurred in the form of phosphor-nickel iron (Schreibersite) in breccia-like fissure fillings in the midst of the basalt, and Törnebohm inferred from this, and from the above mentioned microstructure of the iron-bearing dolerite, that the iron of Disko must have been formed secondarily from solutions. This inference, however, may be questioned, especially in view of the above-mentioned large blocks. The breccia in fact may be due to a basalt zone, broken up by dislocations after the iron had been segregated. From the chemical point of view Törnebohm's theory has recently been strongly supported by C. Winkler[2],

[1] C. Winkler: 'Zur Zusammensetzung des Eisens von Ovifak,' etc. *Kongl. Vetensk Ak. Förh*, 1901, No. 7, Stockholm, p. 495.

[2] C. Winkler: 'On the Possibility of the Immigration of Metals into Eruptive Rocks through the Agency of Carbon Dioxide.' *Ber. d. Math.-Phys., Kl. d. Kgl. S. Ak. d. W.* Leipzig, 1900, p. 9.

who has called attention to the freely fluid compounds which, according to recent investigations, carbon dioxide forms with nickel-iron on even moderate heating, and which decompose again, with separation of the native metals. Such heating might take place for a considerable time at the contact of such gases with an eruptive body still undergoing congelation. The author himself, it is true, raises the difficult question as to the origin of such iron carbon compounds which must have been formed in a cooler zone. The geologic conditions of these and other closely related occurrences indicate that the original seat of the native metals was in the eruptive hearths themselves.

R. J. V. Steenstrup subsequently found in basalts, at several other points of Disko, inclusions of native iron, graphite and nickeliferous magnetic pyrite, which renders it very likely that the iron and nickel content was an original constituent of those basaltic magmas, and the masses are not of cosmic origin, as Nordenskiöld had originally conjectured.

2. *Segregations of Nickel Iron in Olivine Rock and Serpentine of Awarua in New Zealand.*

A very interesting occurrence of nickel iron, awaruite, discovered on the west coast of the south island of New Zealand, by W. Skey, in 1885, has been described by G. H. F. Ulrich[1]. This region consists of gneisses, mica schists and chloritic schists, which are broken through by vast stocks of an olivine rock of the composition of saxonite (olivine + enstatite), in part transformed to serpentine. In the river valleys, descending from the mountains formed of serpentine and saxonite, the nickel iron was found in loose grains, and it was intended to wash it from the gravel. Subsequently it was also found in small particles intergrown with the eruptive rocks just named. The composition of awaruite, according to Skey, is as follows:

Ni	67.63
Co	0.70
Fe	31.02
S	0.22
SiO^2	0.43
	100.00

3. *Segregations of Platinum in Olivine Rocks.*

It had long been suspected that the platinum of the Ural placer gravels (see later) must have its original source in the serpentines and olivine rocks found in the region drained by the upper courses of the platinum-carrying rivers. This inference became a certainty when an olivine gabbro

[1] G. H. F. Ulrich: 'On the Discovery, Mode of Occurrence, and Distribution of the Nickel Iron Alloy, Awaruite, on the West Coast of the South Island of New Zealand.' *Quart. Journ.* Geol. Soc. London, 1890, Vol. XLVI, pp. 619-633.

with grains of intergrown platinum was discovered on the Krestovozdrischensky property, in the western Ural, and later, in the eastern part of the mountains in the Goroblagodatsk district, nests of chromite with platinum were found in an olivine rock[1].

Extensive experiments with crushed samples of olivine rock and olivine gabbro from the vicinity of Mount Soloviov, near Nizhni Tagilsk, have shown a slight platinum content in these rocks.[2]

The platinum of the Ural contains 5 to 13% of iron, besides some iridium, rhodium, palladium, osmium and copper. (See platinum gravels.)

St. Meunier[3] calls attention to the very irregular and often branched forms of the grains of iron-platinum in the olivine rocks of the Ural, and compares it with the peculiar structure of the small nests of native iron in the dolerite of Ovifak and the iron grains in meteoric magnesian silicate rocks. By experiment he obtained similar structures by using gases to reduce the respective metals from a heap of granules of such silicates. A jet of platinum chloride, hydrogen and some ferrous chloride passing through the heap at red heat produced iron platinum in quite analogous development. These observations are important. The conclusion he draws from them, however, that the rocks in question are products of primitive congelation, after the manner of meteorites, is not borne out by the conditions under which the platinum-bearing eruptive rocks actually occur.

The platinum contents of the olivine rocks of the Ural have, with few exceptions, been found much too low to give to these primary platinum deposits an economic significance; only the residual and alluvial placers pay for the working.

4. *Gold as a Primary Constituent of Eruptive Rocks.*

Though it may be difficult in an individual case to decide whether the particles of native gold found in eruptive rock are primary and really due to segregations or have been introduced by secondary processes, yet a series of occurrences seems to indicate the probability of the former alternative. Most of the observations relate to granites and other acid eruptive rocks.

G. P. Merrill[4] describes primary free gold occurring as an inclusion of

[1] A. Inostranzeff: 'Primary Site of Platinum in the Ural.' *Mitth.* an d. Ges. d. Naturf, in St. Petersburg. Nov. 7, 1892. (Reviewed by R. Helmhacker. *Z.* f. pr. G., 1893, p. 87.)

[2] Oral communication of Mining Engineer Hamilton of Nizhni Tagilsk to R. Beck when on a visit to Mount Soloviov in 1897.

[3] St. Meunier: 'Study of the Matrix of the Platinum of the Ural,' etc. *Compte Rendu du VII. Congr. Geol. Intern.*, 1898, p. 157.

[4] G. P. Merrill: 'Occurrence of Free Gold in Granite.' *Am. Jour. Sci.*, 1896, I, p. 309. H. Schultze: 'Gold Mining,' in H. Kunz's 'Chile.' 1890, p. 78. W. Möricke: 'The Gold, Silver, and Copper Ore Deposits of Chile.' Freiburg, 1898, Vol. I, p. 16.

feldspar and quartz in a granite from Sonora, Mexico, as "a product of cooling and crystallization from the original magma." H. Schultze demonstrated the primary nature of gold in many granites of the coast Cordillera of Chile; W. Möricke proved the same for glassy and crystalline quartz trachytes of that country; W. P. Blake added examples from Arizona; Forbes, examples from Bolivia. It also seems that the primary nature of the gold in the granites in the Ekaterinburg region in the Ural, as, for example, on Lake Shartash, has been satisfactorily demonstrated. These occurrences are, however, only of economic importance because payable placer gravels may develop from them.

On the other hand, the primary content of free gold in diorites or amphibolitized diabases, so often referred to in different publications, seems of very doubtful authenticity. The occurrences of this kind examined by us, for example, from Mashonaland, rather suggest the assumption of a secondary immigration of gold. The reader will find further statements on this subject on a subsequent page.

In connection with this it may be mentioned that according to R. Daintree[1] gold-bearing pyrites are found widely distributed in the diorites which occur in the Upper Silurian or Devonian of New South Wales, Victoria and Queensland. The primary nature of these pyrites is not, however, evident from the accompanying plates of thin sections.

A remarkable case is that mentioned by K. Schmeisser[2], of gold in a basalt from Richmond river in New Zealand, which is said to assay as high as 18 grams per ton. This may be a local occurrence and due to highly auriferous sands gathered from gravels which were broken through by the basalt.

(B) Segregations of Metallic Oxides in Eruptive Rocks.

Table of the Important Iron Ores.

Ore.	Fe.	H_2O.	CO_2.	S.
Magnetite FeO, Fe_2O_3	72.4	.....	.....	.....
Hematite (Specular ore) Fe_2O_3	70.0	.....	.....	.....
Siderite (Spathic iron ore) $FeCO_3$	48.27	.....	37.92	.....
Limonite, $2Fe_2O_3.3H_2O$	59.89	14.4	.....	.....
Pyrite, FeS_2	46.7	.....	.....	53.3

[1] R. Daintree: 'Occurrence of Gold in Australia.' *Quart. Journ.* Geol. Soc., 1878, Vol. XXXIV, p. 431.

[2] K. Schmeisser: 'Australasien,' p. 92.

1. *Segregations of Magnetic Iron Ore in Quartz-free Orthoclase Porphyries and Syenites.*

This group includes the best studied and authenticated magmatic deposits known, especially the famous deposits of the Ural[1] and of Lapland, which we will describe in detail.

(a) The Vysokaya Gora.

The famous iron ore deposit of Vysokaya Gora (High Mountain) lies directly west of Nizhni Tagilsk, the most important mining locality of the central Ural. It is merely one link in a chain of similar magnetite deposits of these mountains, which are all associated with a series of syenite and accompanying porphyritic rocks covering an area about 70 kilometers long and 15 kilometers broad, and striking north-south. The main mass of the Vysokaya intrusion consists of augite-syenite, which in many instances alternates with bands of a quartz-free orthoclase porphyry. The latter rocks consist of orthoclase feldspar and a little plagioclase; it is only here and there that augite (or uralite) and biotite take part in their composition. Besides the accessory ingredients (titanite, zircon and apatite), magnetite is also found in small granules or rounded crystals, which may constitute as much as 20% of the entire rock mass, until finally whole lumps of this mineral make their appearance, thus gradually effecting the transition to true orebodies and forming an irregular stock. At times, as, for example, in the fragments of a breccia due to later disturbance, the result of igneous energy, the orthoclase porphyry is amygdaloidal and shows primary magnetite concentrated around vesicular cavities now filled with calcite (Högbom). According to Tschernyschew, there is a connection between the dislocations and the epidote-zoisite-garnet rocks of the Vysokaya, which, besides these minerals, contain also zeolites, chlorite, quartz and calcspar. According to Högbom their structure shows them to be metamorphosed porphyries and syenites, since they still show feldspar lathes arranged in a fluidal structure. These eruptive masses are intruded in Devonian limestones, the rocks being well exposed in the open-cuts made in mining. Greatly decomposed interbedded tuffs occur with these limestones, especially in the eastern part of the mountain. The sedimentary strata are faulted, bringing the eruptive rocks and orebodies in contact with the tuffs and epidote-garnet rock masses along the fault plane.

[1] H. Müller: 'Ueber den Magnetberg Gora Blagodat.' *Berg u. Hutten Zeit.*, 1866, p. 54. P. Jérémeew: 'Les minerais de fer dans les districts miniers de la chaîne de l'Oural.' *Journ. d. Mines*, 1859, II., p. 313. Th. Tschernyschew: 'Guidebook of the Excursions of the VII. International Geological Congress, 1897.' Vol. IX. A. H. Högbom: 'Om de vid syenit bergarter bundna jernmalmerna i Ostra Ural.' *Geol. Foren.* i Stockholm Förh. Vol. XX, part 4, 1898.

The magnetic iron ore of Vysokaya is remarkable for its great purity. The ore has averaged 65 per cent during the past ten years. A large part of the ore that is mined has the composition of martite.[1] The ore is low in phosphoric acid compared with the analogous deposits at Lébiáshaya situated farther northeast, near Nizhni Tagilsk. The Vysokaya iron ores at times contain scattered grains of copper pyrite. To the southeast of this mountain of magnetic iron ore is the famous copper mine of Médnorudiansk. The characteristic analysis of the ore of the Vysokaya given below is from the official report of the company operating the mines:

Fe_2O_3	74.40	Fe 66 per cent
FeO	16.71	
Mn_3O_4	1.30	
Cu	0.06	
S	Trace	
P	0.03	
SiO_2	2.85	
Al_2O_3	1.80	
CaO	0.99	
MgO	0.98	
	100.12 per cent.	

The iron industry of Nizhni Tagilsk was founded about 1725 during the reign of Peter the Great. The mines supply half a dozen furnaces in the Ural district with ore, the average annual production during the past decade being a little over 100,000 tons.

(b) The Goroblagodat Iron Deposit.[2]

This famous mountain of magnetic iron ore, whose name means "blessed mountain," is an isolated peak rising to a height of 156 meters above the Kushva plain. The deposit supplies extensive reduction works, and is worked by vast open-cuts which run around the south side of the summit, and in terraces far down the west slope. A high pillar of rock has been left at the summit which is crowned by a chapel. (See Fig. 1.) The view from this point includes the range of the Ural, which here is not very high, to the west, while eastward the Tura and Tagil rivers are seen traversing the gently undulating west Siberian lowlands.

At Blagodat the same conditions seen at Vysokaya are exactly repeated, except that the arrangement of the orebodies proper is somewhat different. Here they have the form of streaks arranged in benches, one above the other, as shown in Fig. 1. This figure also exhibits the two main faults of the deposit. The transition between ore and normal eruptive rock is gradual and not sharp as represented in the figure.

[1] G. Lebedew: 'Lehrbuch der Mineralgi' (Russian), St. Petersburg, 1900, p. 126.
[2] Literature the same as under Vysokaya Gora.

In contrast with the Vysokaya ores, the magnetite contains much pyroxene and its chloritic decomposition products, as well as spinel, so that the percentage of iron is considerably lower, being on an average only 55%. On the other hand the quality is excellent because of the very small percentage of phosphorus and pyrite.

Mining began at Blagodat the early part of the last century, and the output reached 16,000 tons as early as 1770. From 1813 to 1898, 2,720,000

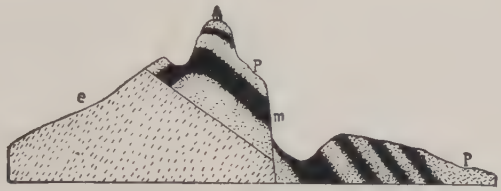

Fig. 1.—Section of Goroblagodat after Th. Tschernyschew.
p, orthoclase porphyry; m, magnetic iron ore; e, epidote-garnet rock.

tons of ore were taken from this mountain. In 1898 the production was 66,000 tons.

A characteristic analysis of the ore according to D. J. Mendelejeff[1] is given below:

SiO_2	9.40 per cent.	
Al_2O_3	7.18	
Mn_2O_3	0.20	
FeO	21.65	Fe 53.89 per cent.
Fe_2O_3	52.93	
CaO	6.00	
MgO	1.62	
S	0.05	
SO_3	0.12	
P_2O_5	0.33	
Cu	0.01	
Moisture	0.20	

The amount of ore exposed and ready for extraction in 1890 was estimated to be 15,000,000 tons. The ore is treated in the furnaces of Kushva, Barancha and Verhneturye, the pig iron being shipped to Nizhni Turinsk and Perm. The chapel on the summit is dedicated to the memory of Vogul Stephen Chumpin, who revealed to the Russians the wealth of the mountain, and for doing so was burned alive by his tribe on the summit.

A third iron deposit in the southern Ural, 60 to 70 kilometers south of Verhne Uralsk, called Gora Magnitmaya, or Atach, seems to be connected with porphyritic and syenitic masses, but detailed geologic investigations have not yet been made. The ores contain 67 to 68% of iron and are almost free from phosphorus and sulphur.

[1] 'Iron Furnace Industry of the Ural in 1899.' II, p. 174. (In Russian.)

The iron deposits of Kiirunavaara and Luossavaara in Lapland are of the Ural type just described[1]. They have been recently investigated in detail and actively developed.

(c) Kiirunavaara and Luossavaara.

These two great deposits are situated in the Swedish province of Norrbottom, in about 67° 50′ north latitude. The ores form great stocks, reminding one of strata by the manner in which they outcrop within a vast mass of quartz-free orthoclase porphyry. This rock is bounded on the east by graywacke slate, clay slate and conglomerates, overlain by quartzitic sandstones, while on the west it abuts against strongly metamorphosed conglomerates.

The ore stock of Kiirunavaara forms a barren mountain ridge, the outcrop extending for 1½ miles, while magnetic observations prove its continuation northward to the shore of Lake Luossajarvi, and out as far as an island, so that the entire length must be nearly three miles. Throughout its entire extent the deposit dips uniformly eastward at from 45° to 80°, as determined by drilling. The thickness of the ore sheet is between 34 and 150 m. (111 and 500 feet) and averages 70 m. (230 feet). The total amount of ore available for extraction is estimated by Hjalmar Lundbohm to be at least 215,000,000 tons. This ore is not everywhere of the same quality. The author just named distinguishes five types with many intervening transitions: (1) Magnetic iron ore, poor in phosphorus; (2) the same, mixed with hematite; (3) phosphorus-bearing magnetic iron ore, with a little apatite; (4) highly phosphoritic magnetic iron ore, with apatite, in numerous pockets, stringers and stratiform bodies; (5) highly phosphoritic magnetic iron ore with minutely divided apatite. In more than 60% of the samples from the very numerous prospects the iron exceeded 67%, while the phosphorus varied between 0.05 to 6%.

The ore mountain of Luossavaara lies north of Lake Luossajarvi, and forms a broad stratiform stock about ¾ of a mile long by about 180 feet broad, dipping steeply east within the same porphyry mass. This deposit is estimated to contain at least 4,700,000 tons of ore carrying 67 to 70.5% iron and a very low phosphorus content. These occurrences will become of great importance upon the completion of the railway which will extend from the Lapland iron ore region across to the Ofoten Fjord, on the west coast of Norway.

[1] K. A. Fredholm: 'Rocks and Ores in Luossavaara and Kiirunavaara.' *Geol. Fören. Förh.*, 1891, Vol. XIII, p. 266. Hj. Lundbohm: 'Kiirunavaara and Luossavaara Iron Ore Field.' Geol. Surv. of Sweden, series C, No. 175, 1898, with 3 plates and 1 map.

2. *Segregations of Titaniferous Magnetite*[1] *in Gabbro.*

The most important examples of this class are the deposits of Taberg and Routivare in Sweden, Valimaki in Finland and the Adirondacks in New York. Kemp has published a review of all known deposits of this class[2].

The genesis of these segregation deposits has been discussed by Vogt[3]. He has attacked the problem by a study of numerous analyses of rocks and ores which have been platted in tables giving a graphic representation of the relations of the different elements. One of these tables, reproduced in Fig. 2, shows how, in the transition stages from normal rock to segregated ore, the amount of Fe_2O_3 and TiO_2 increases as the silica, lime and alumina decrease. The magnesia increases, attains a maximum in the middle transition forms, and afterwards decreases. Vogt infers from these relations that the real solvent of the ores must be an alumina-lime-sodium-silicate, and that this silicate plays the same part as the mother liquor of saline solutions. A part of the silica is, however, supposed to have taken part in the differentiation as a silicate of magnesia and iron. Petrographic investigations confirm these conclusions. Kemp has recently reviewed the evidence and presented his conclusions[4].

(a) The Taberg Near Jonkoping.

The iron deposit of Taberg[5] in Smaland, southwest of Lake Wetter, near Jonkoping, in Sweden, is a belt or streak of ore-rich rock forming a part of a mass of olivine gabbro (olivine hyperite or Törnebohm). This basic rock has by reason of its greater resistance been left during the degradation of the region as a residual mountain. The iron ore forming this mountain consists of titaniferous magnetite and olivine, with subordinate admixtures of biotite and plagioclase. Transitions may, however, be observed, showing all gradations between the magnetite-olivenite occupying the center of the igneous stock, to the ordinary olivine-gabbro, poor in magnetite, forming the border of the intrusive mass. The stock is intruded

[1] J. F. Kemp: 'Titaniferous Iron Ores of the Adirondacks.' 19th *Ann. Rept.* U. S. Geol. Surv., III, 1899, p. 387.

[2] J. F. Kemp: 'A Brief Review of the Titaniferous Magnetites,' *School of Mines Quarterly*, 1899, July, pp. 323-356, Nov., pp. 56-65.

[3] J. H. L. Vogt: 'Further Researches upon the Segregation of Titaniferous Iron Ores in Gabbro.' *Zeit. f. Prak. Geol.*, 1900-1901.

[4] *The Engineering and Mining Journal*, November 28, 1903.

[5] A. Sjögren: 'On the Occurrence of the Iron Ore of Taberg in Smäland.' *Geol. Fören. Förh.*, 1876 and 1877, p. 42, with older literature. *Ibid.*, 1882-1883, p. 264. A. E. Törnebohm: 'On Taberg in Smäland,' etc. *Ibid.*, 1880-1881, p. 610, plates 25 and 26. J. H. L. Vogt: 'Formation of Ore Deposits by Differentiation,' etc. *Zeit. f. Prak. Geol.*, 1893, p. 8.

in a complex of gneisses and gneiss granites, and is accompanied by hornblende schists, probably patches of dynamo-metamorphosed gabbro.

The Taberg ore is characterized by the presence of 0.12 to 0.40% of vanadic acid; in fact, the element vanadium was first discovered by Seffstrom

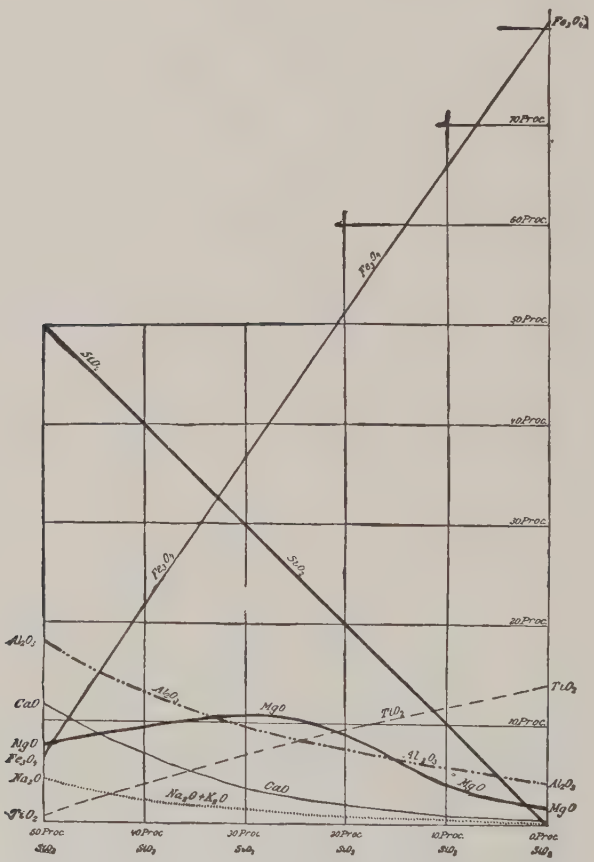

Fig. 2.—Diagram showing Normal Differentiation. (Vogt.)

in 1830 in the crude iron of Taberg. The high percentage of titanium greatly lowers the value of the Taberg ore; moreover, the iron content, even at the richest spots, is low, not exceeding 32 per cent.

(b) The Titaniferous Magnetites of the Adirondacks.

Among the North American representatives of this type of deposit the Adirondack iron deposits are the best known, and have been carefully

studied and described by Professor Kemp.[1] The mines of the Adirondack region are in Essex county, New York, southwest of Lake Champlain.

The older gneisses and crystalline limestone of this region contain many intrusive masses of gabbro and closely related rocks which have been altered by regional metamorphism to schistose rocks.

These rocks include both anorthosites (coarse-grained rocks of almost pure labradorite) and the dark-colored gabbros and norites in which the ferromagnesian silicates predominate. These extreme types are both connected with masses of titaniferous magnetite and menaccanite, the former at Newcomb, Wilmington and North Hudson, the latter at Crown Point, Elizabethtown, etc. The minerals of the normal gabbro occur disseminated through these ores, and all transitions occur from gabbro to ore.

The petrographic features as described by Kemp correspond closely to those of Välimäki, Finland. The following analysis by Hillebrand, of the typical ore from Oak hill, represents the normal composition of this class of ores:

Fe	38.98	Al_2O_3	7.03
Fe_2O_3	30.34	CaO	3.59
FeO	22.81	MgO	6.92
TiO_2	5.21	P_2O_5	0.14
SiO_2	21.42	S	0.04

The iron deposits of the Mesabi range, Minnesota[2], Port Henry and Lake Champlain[3], New York; Iron Hill, Cumberland, Rhode Island[4], and those of various gabbro areas of Quebec[5] and Ontario[6], all belong to this class.

The magnetite and chromite deposits of the Zwartkoppies range and elsewhere in the Transvaal, Africa, occur in norites forming the contact facies of a red granite. They are regarded as magmatic segregations by Molengraaf[7].

Similar occurrences, though of less extent, have been found at several points in Sweden; for example, in the gabbro of Langhult in Smaland and of Ransberg in Vestergotland.

[1] J. F. Kemp: 'The Titaniferous Iron Ores of the Adirondacks.' 19th *Ann. Rept.* U. S. Geol. Survey, Part III, 1899, p. 383.

[2] N. H. and H. V. Winchell: 'The Iron Ores of Minnesota.' Geol. Surv. of Minn., 1891.

[3] Kemp in *Trans.* Am. Inst. Min. Eng., Vol. XXVII, pp. 146-203, 1898.

[4] M. E. Wadsworth: 'A Microscopic Study of the Iron Ore Peridotite of Ironmine Hill.' *Bull.* Mus. Comp. Zool. Harvard College, Vol. VII, 1881, p. 183.

[5] F. D. Adams: 'On the Igneous Origin of Certain Ores,' Montreal, 1894. *Proc.* Gen. Min. Assoc. of the Province of Quebec, Jan. 12, 1894.

[6] E. J. Chapman: 'On Some Iron Ores of Central Ontario.' *Trans.* Royal Soc. Canada, 1885, p. 9.

[7] 'Geol. Aufnahme der Süd-Afrikanischen Republik.' *Jahresber.* for the year 1898. Pretoria, 1900, p. 14. 'Géol. de la Rép. Sud-Africaine,' 1901, pp. 48 and 52.

(c) Deposit of Routivare in Norrbotten, Sweden[1].

This great deposit occurs in a gabbro (gabbro diorite) which has been subjected to strong regional metamorphism. The deposit forms a band 1,600 meters long by as much as 300 meters broad, consisting of titaniferous magnetite, menacconite, spinel, olivine, a pyroxene and some magnetic pyrite. The ore differs from that of other similar deposits, as it contains a large amount of spinel. It contains between 48 and 52% of iron and between 11 and 13% of titanic acid. Other magmatic deposits of similar ores rich in spinel occur in Norway and have been described by Vogt[2]. From his study of these ores in thin section under the microscope he has reached the important conclusion that the iron magnesian silicate has been the first to separate out of the magma, followed by the titaniferous magnetite. If the ores also contain pyrite and spinel the order of crystallization is: Pyrite, spinel, titaniferous magnetite, an exception to the usual order observable in eruption rocks, in which magnetite is the first mineral to separate out.

Between Sordavala and Pitkaranta, on the northeast shore of Lake Ladoga, near the village of Valimaki, a rock-complex consisting of phyllite, quartzitic schist, nodular and hornblende schist, together with mica schist carrying andalusite and staurolite, is penetrated by a coarse-grained diorite which is apparently an altered gabbro.

According to Blankett[3] this gabbro diorite forms a stock, having a north-south direction, cutting the schists and enclosing metamorphosed portions of them. The rock consists of plagioclase, hornblende (at times with augite core) with some epidote, apatite, magnetite, muscovite and hematite. Within this intrusive mass at some distance from its contact with the schists there are basic streaks of a rock very rich in hornblende, diallage, bronzite, olivine and titaniferous magnetic iron ore, with subordinate amounts of green spinel, pyrite, magnetic pyrite, copper pyrite, mica and apatite. These dark streaks as a rule contain 15 to 30% of iron, while richer portions run as high as 40%. One specimen contained 63.40% of ferric oxide and 2.90% of titanic acid. All possible transitions from poor to rich ore may be found within these very extensive segregation streaks, whose distribution is usually quite regular. The iron ore is crushed and the magnetite extracted by magnetic separators, the concentrate being briquetted and smelted at

[1] W. Peterson: 'On the Iron Ore Field of Routivare in Norrbotten Lane.' *Geol. Fören. Förh.*, Vol. XV, 1893, p. 45, with map. H. Sjögren: 'Additional Notes on Routivare Iron Ore.' *Ibid.*, p. 140.

[2] Vogt: *Zeit. f. Prak. Geol.*, 1900, pp. 233-242. Kolderup: 'Petrog Beschreibung Lofatens,' etc. *Bergens Mus. Aarbog*, VII, 1898, pp. 1-54.

[3] Blankett: 'Ore Field of Välimäki, etc.' *Geol. Fören. i Stockholm Förh.*, 1896, p. 201, with map.

Widlits on the opposite side of the lake. The mines produced some 7,764 tons of ore fit for smelting in 1896.

In other cases the magnetite is not only accompanied by spinel, but also by corundum and sillimanite, as in the norites of Westchester county described by G. H. Williams.[1]

3. *Segregations of Titaniferous Magnetite Iron Ore in Nepheline-Syenites.*

The iron deposits of Alnö, near the east coast of Sweden, in the Gulf of Bothnia, are described by A. G. Högbom[2] as basic segregations of nepheline-syenite. The nepheline-syenite of that locality shows an extraordinary number of varieties, and is closely associated with remarkable masses of crystalline limestone which, according to Högbom, are possible primary segregations from the extremely basic magma. The surrounding rocks are gneisses which have been altered by contact metamorphism. The basic streaks of the nepheline-syenite are distinguished by large amounts of titano-magnetite, abundant apatite, many silicates of iron and magnesium, as well as the absence of feldspar and, ordinarily, also of titanite, nepheline and cancrinite. Some portions are so rich in titano-magnetite as to be workable. Such an ore from the Tryg mine had, according to A. Tamm, the following composition:

SiO_2	3.10
TiO_2	12.14
Al_2O_3	Trace.
FeO	8.95
Fe_2O_3	64.38
MnO	1.15
CaO	2.30
MgO	8.00
S	0.07
P_2O_5	Trace.
Total	100.09

An occurrence in Brazil, which possibly may be much younger in age, is most naturally mentioned here. According to O. A. Derby[3] and E. Hussak,[4] the magnetic deposits of the Jacupiranga and Ipanema mines in the province of Sao Paulo are segregations in granular pyroxenic rocks. The deposits of magnetite-pyroxenite (jacupirangite) with 60 to 70% of magnetite are, moreover, closely connected by transition forms with nepheline

[1] G. H. Williams: 'The Iron Ore and Emery in the Cortlandt Norites.' *Am. Jour. Sci.*, Ser. III, Vol. XXXIII, 1887, p. 194.

[2] A. G. Högbom: 'On the Nepheline-Syenite Area of the Island of Alnö.' *Geol. Fören. Förh.*, Vol. XVII, 1895, pp. 100-214.

[3] O. A. Derby: 'On Nepheline Rocks in Brazil.' *Quart. Journ.* Geol. Soc., 1891, Vol. XLVII, p. 251.

[4] E. Hussak: 'On Brazilite,' etc. *Neues Jahrbuch f. Min.*, 1892, Vol. II.

rocks. The iron-bearing streaks also contain, besides magnetite and pyroxene, nepheline, perofskite and apatite, as well as brazilite, a tantaloniobate.

4. *Segregations of Titanic Iron Ore in Gabbro Rocks.*

Segregations of titanic iron ore in gabbro are less numerous than the magnetites just described. Such occurrences have been described in great detail by J. H. L. Vogt[1] and Kolderup, from whose description the following abstract is given:

The Titanic Iron Ore Deposits of Ekersundsoggendal.

In southern Norway, in the Ekersund-Soggendal district, the crystalline schists are broken through by a norite intrusion forming a mass 1,200 square kilometers in extent. The eruptive rock shows a great variety of development with all possible transitions between pure labradorite and norites rich in hypersthene, apatite and enstatite-granite or bronzite-granite.

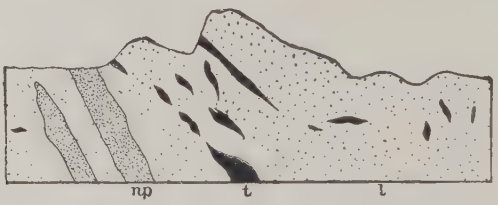

Fig. 3.—Section through the Blaafjeld. (Vogt.)
l, labradorite; np, dikes of norite-pegmatite; t, titanic iron ore.

The labradorite contains veins and nests of pure titanic iron ore up to masses of 11 meters in thickness and 50 meters in length, as at Blaafjeld, illustrated in Fig. 3 after Vogt. The boundary between the ore and the labradorite is sometimes sharp, sometimes the reverse. Furthermore, the labradorite is traversed by dikes of a norite very rich in titanic iron ore. The rock of these menacconite-norite lodes consists of a granular crystalline aggregate of titanic iron ore, hypersthene and some labradorite. It contains as accessories, chrome-spinel, iron pyrite and very scanty apatite. The large lode (Storgangen) about 3 kilometers long and 30 to 70 kilometers wide, which is represented in Fig. 4, contains on an average 40% of titanic iron ore, and in some of its dark bands parallel to the selvage even 70 to 80 per cent.

[1] J. H. L. Vogt: 'Norske erts Forekomster.' *Arch. f. math. og naturv.* Christiania, 1887, Vols. X and XII, p. 101. Reviewed in *Neues Jahrbuch f. Min.*, 1899, Vol. II, p. 97. Also, 'Om dannelse af jernmalm forekomster.' Christiania, 1892. Also Bildung von Erzlagerstätten.' *Zeit. f. Prak. Geol.*, 1896, p. 6. Kolderup: 'The Labrador rocks of West Norway. Bergen's *Mus. Aarbog*, 1896. No. 5, pp. 159-181.

5. *Segregations of Chrome Iron Ore in Olivine Rock and Serpentines.*

It has been known for a long time that all large deposits of chrome iron ore[1] are associated with serpentine. It might be readily imagined that all these ores were segregated during the serpentinization of olivine rocks. Indeed, it is probable that a part of the chromite masses enclosed in serpentines was formed during this process of rock alteration, since it is known that certain original ingredients common in olivine rocks, especially chrome diopside and chrome spinel, or picotite, contain chromine in considerable amount. Just as magnetite is segregated during the alteration of iron-

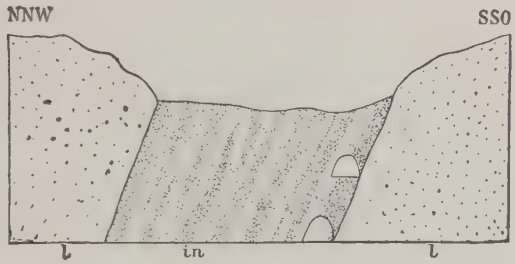

Fig. 4.—Profile through the Storgang. (Vogt.)
l, laboradorite; in, ilmenite-norite with dark streaks very rich in ore.

bearing silicates, as, for example, of olivine into serpentine, so in the decomposition of chrome diopside, and other chromine containing silicates, chrome iron ore may be formed. However, this origin, as already noted, holds true for only a part of these ores, not for all. On the contrary, the discovery of segregations of chromium ores in entirely fresh olivine rocks proves that in the main the chrome iron ore represents a segregation in the original magma. This has been shown very convincingly by Vogt[2].

The most important chrome iron mines, arranged according to their approximate figures of production, are scattered over the earth at the following places: In Asia Minor[3] (Harmandjyk, Brussa, vicinity of Smyrna); in the Ural (district of Ekaterinburg and Nizhni Tagilsk); in California; in North Carolina (Ashe and Clay counties); in Pennsylvania and Maryland; in New Caledonia (Tiebaghi Mountains at Mount Dore); in New Zealand; in Greece (Burdaly and Thessaly on Skyros); in Styria (Krau-

[1] According to Vogt the total annual production of chrome iron ore for the entire world is only 20,000 tons. It is used for chrome steel, dyeing, etc. (The U. S. imports for 1902 amounted to 20,000 tons; the world's production to 30,000 tons.—W. H. W.)

[2] J. H. L. Vogt: 'Zur Classification der Erzvorkommen,' *Zeit. f. Prak. Geol.*, 1894, p. 384.

[3] K. E. Weiss: 'Lagerstätten im West. Anatolien,' *Zeit. f. Prak. Geol.*, 1901, p. 250

bath); in Bosnia (Dubostica); and in Norway (island of Hestmando, vicinity of Röros). Within the German Empire the inconsiderable occurrences of Silberg and Grochau in Silesia are the only ones known.

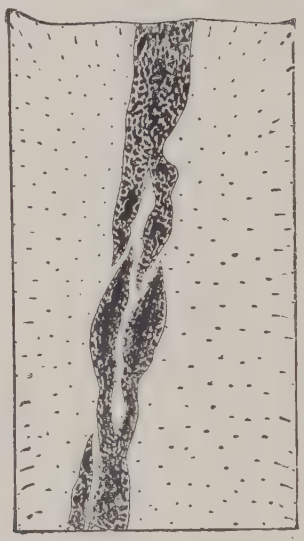

Fig. 5.—Section of a segregation band of chromitiferous olivine rock in the saxonite of Varnasfjeld. (Vogt.)
Length of lode 40 to 50 meters; thickness 0.1–0.8 meters.

Fig. 6.—Profile of a segregation band (streak) of pure chromite and chromitiferous olivine rock in saxonite; streaks rich in enstatite with nests of chromite seen below. Ramberg on Hestmandö. (Vogt.)
Streak lode, 5 to 7 meters long; 0.5 to 0.8 meters thick.

Under this heading we will merely mention a few instances that have been accurately investigated.

From a genetic point of view decidedly the most interesting are the Norwegian occurrences studied by Vogt[1].

(a) The Chrome Deposits of Hestmando and Other Localities in Norway.

The island of Hestmando lies in northern Norway under the Polar Circle. Here the gneiss rock is intruded by at least a dozen small stocks of olivine rock, at most, 0.3 mile in diameter. They consist of olivine, enstatite, chrome-spinel and chromite. Sometimes they also contain a colorless or greenish actinolite, various mica-like minerals and as secondary

Fig. 7.—chromitiferous olivine rock of Ramberg. (Enlarged 50 times.)
o, olivine; ch, chromite.

formations magnesite and talc. According to the usual petrographic classification the rock would have to be called a saxonite. It varies from enstatite-poor to enstatite-rich rocks, so that the extreme types might be designated as enstatite-bearing dunite and enstatite rock. Within these olivine rocks the chrome iron ore forms streak-like, that is to say, ill-defined bands and lumps, or lode-like zones consisting of many such lumps as shown in Fig. 5 and 6, after Vogt. On the boundaries of such segregations, where the chromite masses are shown to be connected by transitions with the normal olivine rock, the microscope reveals the chromite as shown in Fig. 7, with well developed crystalline forms defined against the olivine. The segregation of ore must undoubtedly have taken place before the crystallization of the olivine.

From observations upon about 40 chromite deposits in olivine rock or

[1] J. H. L. Vogt: *Zeit. f. Prak. Geol.*, 1894. p. 389.

serpentine in Norway, Vogt infers that the size of the ore occurrences is about proportional to the magnitude of the respective eruptive stocks; thus the largest orebodies are found at Feragen and Rödhammer, near Röros, where they have been traced to a depth of about 50 meters, being at the same time within the largest serpentine fields.[1]

(b) *The Chromite Ore Deposit of Kraubath in Upper Styria.*

These conditions also obtain at the well known Kraubath[2] deposits whose genesis has been recently studied and explained.

The chromite ores of Kraubath, according to F. Ryba, are associated with an olivine rock, forming the remnant of an intrusive mass that rests unconformably on hornblende gneiss. The rock consists mainly of olivine and chromite, and hence must be called dunite. At some points, however, owing to the occurrence of bronzite, it passes over into chromite-harzburgite, which also contains some chrome diopside. As secondary alteration products serpentine masses occur with magnetite and a little brown hematite.

On the right bank of the Mur in the Sommergraben, where the chrome mining industry was carried on, the dunite or the chrome-harzburgite is so little serpentinized that it shows perfectly the character of the olivine rock even to the naked eye. The chromite is scattered through it irregularly, for the most part in octahedrons with more or less rounded edges; more rarely these crystals are crowded closer together, or the chrome iron ore occurs in irregular compact segregations or nests, which have been the objects of much prospect work and long-continued but unsuccessful mining.

The occurrence of the chromite in perfectly fresh olivine rock is also good proof of the magmatic segregation of the ore, the thin sections showing distinctly that the olivine must have been crystallized out later than the larger chromite grains, which look as if they were broken.

6. *Tin-Stone as a Primary Segregation in Granitic Rocks.*

Besides the occurrences of tin-stone as a constant ingredient of greisen (granite without feldspar) which is a rock of secondary origin, this ore is also a primary component of many granites, as, for example, the tourmaline-granite of Eibenstock of the Greifenstein and of Altenberg in the Erzge-

[1] Compare A. Helland: 'Om Kromjernsten i Serpentine,' *Vidensk. Selk. Förh.*, 1873.

[2] A. Miller von Hauenfels: 'Bericht über die geogn. Erforschung der Umgebung von St. Michael u. Kraubath,' V. *Jahresber.* die geogn. mont. V. f. Obersteiermark, pp. 53-76. Also 'Nutzbaren Min.,' etc. *B. u. H. Jahrb.* der k. k. Bergakademie, 1864, Vol. XIII, pp. 214-217. H. Höfer: 'Anal. mehrerer Magnesia ges. der Ober'k,' *Jahrb.* d. k. k. geol. R. A., 1866, pp. 443-446. A. Kahl: 'Der Chrombergbau von Kraubath,' *Berg u. Hutten Jahrb.*, 1869, Vol. XVII, pp. 266-281. H. Wieser: 'Olivin fels von Kraubath,' Tschermak's *Min. Mitth.*, 1872, p. 79. F. Ryba: 'Beitrag zur Genesis der Chromeisenerzlagerstätten bei Kraubath,' *Zeit. f. Prak. Geol.*, 1900, pp. 337-341.

birge. However, these examples have as yet no economic importance, except in so far as the small original granules of these granites, upon the decay of the mother rock, concentrate in and enrich the residual gravels whose chief tin content is, however, derived mainly from the greisen zones. There are no occurrences of primary tin-stone in a granitic rock which is rich enough to mine. A supposed example of this kind which proved an economic failure is found in South Dakota.

The Etta Knob Tin Deposit of the Black Hills, Dakota.

Etta Knob, situated in about the middle of the Black Hills, consists, according to Blake[1], of garnetiferous mica schist, with intervening quartzitic beds, broken through by a granite stock whose nearly circular outcrop measures 30 to 60 meters in diameter. By prospecting it was ascertained that this stock is an upright pillar-shaped mass with a pronounced concentric structure. Next to the country rock there is a sharply defined peripheral zone of dark mica rock with large plates of muscovite, which are workable.

Next inward follows a band of compact quartz, with irregular bunches of compact albite and orthoclase, as well as enormous crystals (up to 12 meters in length!) of spodumene, which lie in the midst of a fine-grained, scaly mass consisting essentially of mica and albite. In this complex mass the cassiterite is interspersed in granules or imperfectly developed crystals, the ore forming about 2.5% of the aggregate. The association of a lithion-pyroxene with tin-stone is also reported from several localities in Maine (E. Richards). Besides the minerals named, the tin-stone of Etta Knob is also accompanied by the following; Apatite, triphyline, tantalite, columbite, arsenical pyrite and copper glance. Besides tin ore spodumene has also been mined.

The Etta Knob rock is a pegmatite which cannot be assumed to have originated as a segregation of the normal granite, but shows, on the contrary, evidence that water had a decided part in its formation.

(C) Segregations of Sulphidic and Arsenical Ores.

The sporadic occurrence of small particles of pyrite in volcanic and plutonic rocks is well known. Iron pyrite in particular is one of the most widely distributed accessory constituents of many eruptive rocks, especially in diabase, diorite and syenite. It appears in entirely fresh undecomposed rocks of this kind under such conditions of microscopic association with

[1] W. P. Blake: 'Tin Ore Deposits of the Black Hills,' *Trans.* Am. Inst. Min. Eng., 1885, Vol. XIII, p. 691. W. O. Crosby: 'Geology of the Black Hills,' etc., *Proc.* Boston Society Nat. Hist., Vol. XXIII.

the other constituents that there can be no doubt as to its primary nature. At times the iron pyrite is replaced by copper pyrite. Thus, the tourmaline-granite of Predazzo, the diabases of the eastern Harz and even the younger lavas of the Alban Mountains at Capo di Bove carry granules of copper pyrite. Variegated copper ore is known from the tourmaline-granite of Kittlisvand in the Norwegian district of Nummedalen. Various sulphidic copper ores also occur disseminated through the syenite of the Plauen area near Dresden, more especially in the dark streaks rich in augite and hornblende, in which native copper, copper pyrite and copper glance often occur, besides other secondary products. Pyrrhotite is often found interspersed in gabbros; it is also observed sometimes in basalts, as at the Landberg, near Tharandt, and on the west coast of Greenland, on Disko, etc. Since, moreover, small crystals of copper pyrite, and, according to J. Scheerer, also another mineral of the same chemical composition, but rhombic form, become segregated before our eyes in smelting operations upon a slow cooling of a siliceous slag, it appears that the magmatic segregation of large bunches, stocks, primary stringers or streaks in the midst of eruptive rocks is *a priori* both possible and probable. According to L. De Launay[1] certain solvents existing under pressure in the magma, such as liquid carbonic acid, alkaline chlorides, fluorides or sulphates, perhaps also water vapor, have taken part in the concentration of such ores from the magma. It is true, however, that the evidence that the deposits of this class are direct segregations from a molten magma, is not as clear and conclusive as it is in the examples of the groups already noted. For many occurrences which are regarded by various authors as direct segregations from eruptive rocks, it will probably be necessary to allow at least a secondary concentration of the ores in the aqueous way, with a partial local transfer of material and an impregnation of the country rock, etc. The great mobility of the sulphide ores, as known from our observation upon them in veins, renders it exceedingly difficult to obtain a clear insight into this matter, especially as a special and detailed microscopic study of the problem has not been made. For these reasons there is grave doubt about the true genesis of such deposits. This is true particularly of the first of the deposits described in this chapter, as magmatic deposits. Recent microscopic study has indeed proved the Sudbury Canada deposits to be metasomatic replacements. There is, therefore, not a single example of magmatic copper deposits known in North America.

[1] *Ann. d. Mines*, 1897, Vol. XII, p. 119 *et seq.*

1. *Deposits of Nickel and Copper Ores in Connection with Gabbro Rocks or Diabases and Their Metamorphic Derivatives.*

The deposits of this class, consisting of nickel-bearing pyrrhotite, chalcopyrite and iron pyrite found in Norway, Canada and some other countries, have in recent years attracted general attention, particularly as a result of the work of J. H. L. Vogt[1]. A brief description of the Norwegian and Swedish occurrences studied by this author is given first, although from an economic point of view they are far inferior to those of Canada.

(a) The Norwegian Nickel Ore Deposits.

Norway contains, according to Vogt, some 40 intrusive masses of gabbro which are distributed uniformly over the country. These rocks are characterized by the presence of nickel ore, whose genetic connection with the gabbro was first described by Th. Kyerulf and T. and J. Dahll. These rock masses, nearly all of which have been strongly altered by regional metamorphism, were, in most cases, formerly regarded as crystalline schists of the same age as the gneisses about them, and the theories concerning the ore deposits were based on this supposition. It is necessary, therefore, to note the decisive observations which convinced the Norwegian investigators of the eruptive nature of this gabbro. The facts are as follows:

1. The boundary between these gabbros and the gneisses or the Cambro-Silurian regional-metamorphic schists is in places very sharply defined.

2. The other rock strata are often truncated and stop at the boundaries of the gabbro.

3. Blocks of schist occur enclosed in the gabbro.

4. Marginal facies, such as orbicular norites, have sometimes been observed.

5. Finally, younger dikes of normal and of pegmatitic gabbro occurring in the gabbro itself bear witness as "subsequent intrusions" and prove the eruptive nature of all these rocks. Their present petrographic character is, it is true, very unlike the prototype, being commonly that of an amphibolite or garnet amphibolite.

Where the original character of these gabbros has not been entirely obliterated by regional metamorphism it is seen that they were at first either olivine gabbros with ophitic structure or true granular-crystalline norites. The ores show a preference for the latter rocks which may or may not carry olivine and show transitions to olivine gabbros.

[1] J. H. L. Vogt: 'Nickel forekomster og nickel produktion,' *Geol. Fören. Förh.*, 1892, pp. 315-338. Also 'Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata,' II, Nickelsulfiderze. *Zeit. f. Prak. Geol.*, 1893, pp. 125-143, 257-284.

The ores connected with the norites consist of:

(1) Magnetic pyrite with 2 to 5%, rarely as high as 10%, of nickel and some cobalt; (2) iron pyrite with some nickel and cobalt; (3) copper pyrite with up to 0.5% nickel and cobalt; (4) titanic iron ore.

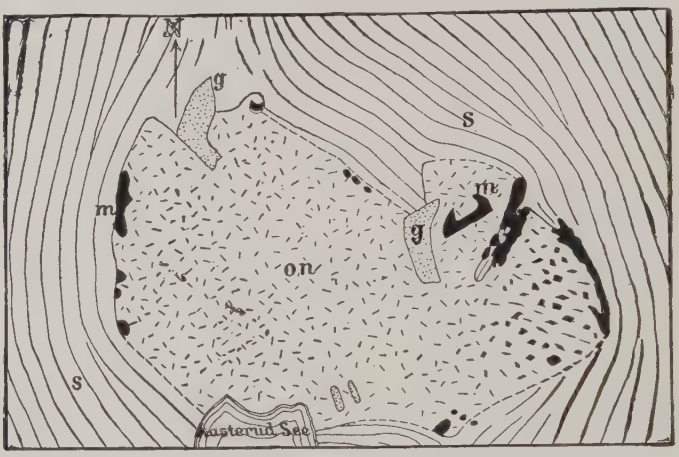

Fig. 8.—Sketch-map of the Erteli mineral region. (Vogt.)
s, crystalline schists; on, olivine norite and other varieties of norite; g, granite; m, ore masses.

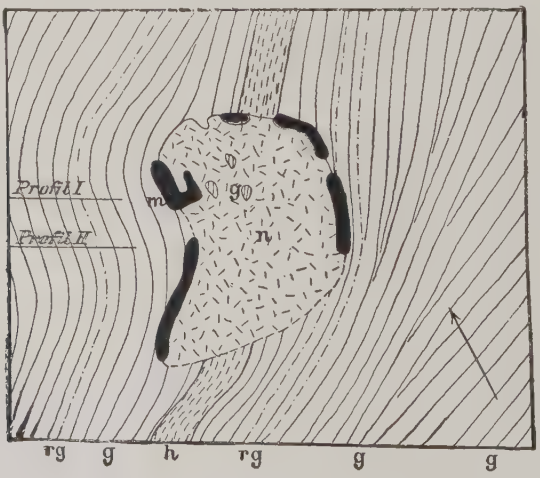

Fig. 9.—Sketch-map of the Meinkjär mining field. (Vogt.)
g, gray gneiss; rg, red gneiss; h, hornblende schist; n, norite; m, orebodies.

The magnetic pyrite always greatly predominates; the iron pyrite sometimes appears to have been segregated earlier than the magnetic pyrite,

since it is embodied in the latter in the form of cubic crystals. Only in very rare cases do we also find iron-nickel pyrite and some other nickel sulphides proper.

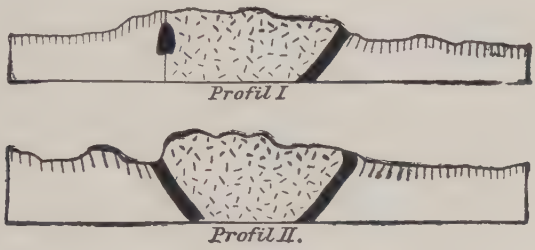

Fig. 10 and 11.—Sections through the norite massive of Meinkjär. (Compare Fig. 9.)

All the ores mentioned are also present in very small amount in fine particles disseminated through the normal norite, while in the deposits proper they form compact ore masses up to 120 or even 200 meters (393-656 ft.) in diameter. These masses have a very irregular shape and are evidently associated with the contact between the gabbros and the country

Fig. 12.—Section of a pyrite vein of Erteli mine No. 1. (Vogt.) n, norite; g, gneiss; m, pyrite mass. Height of section, 5 meters.

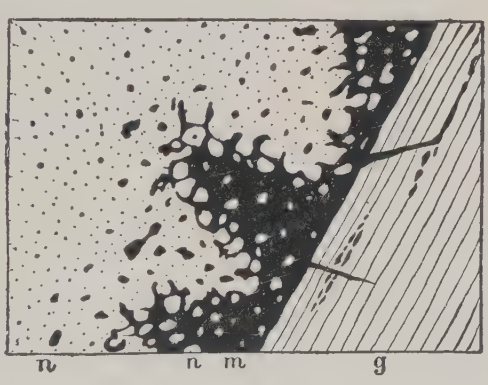

Fig. 13.—Section of a part of a norite contact in the Meinkjär field. (Vogt.) Explanation the same as in Fig. 12. Height of section, 1 meter.

rock. At times they are also found about the borders of enclosed blocks of country rock.

Both these facts are clearly illustrated in Figure 8 (after Vogt), which shows the distribution of the ore masses in the Erteli mining field in the

district of Ringerike, northwest of Drammen. The norite massive of that locality has a longitudinal diameter of about 600 meters. Not less instructive are the figures 9-11 of the Meinkjär mine field (after Vogt).

In some places the pyrite mass passes very gradually into norites poor in pyrite, and finally into almost normal non-pyritiferous norites. In such transition rocks the pyrite often appears in the form of a very irregular venation in the midst of the mass of silicates. Furthermore, the pyrite, as pointed out by Vogt, forms real stringers and lodes which branch away from the orebodies proper, either into the norite or into the country rock, and may also enclose fragments of both. The detailed profile (from Vogt) of the Erteli mine No. 1, in Figure 12, shows these relations very distinctly.

Fig. 14.—Nickel ore of Varallo under the microscope, with fifty-fold enlargement. d, diallage; p, plagioclase (with crossed nicols); m, magnetic pyrite.

A second profile of the same kind from Vogt, from the Meinkjär mine in Bamle, northwest of the island of Kragero, Figure 13, shows how the pyrite has penetrated the neighboring gneiss parallel to the stratification so that we here find perfectly isolated patches of ore and fahlband-like impregnations of larger rock bodies.

According to Vogt the pyrite is a direct differentiation product of the noritic magma, a fractional part of the magma whose melting point is somewhat lower than that of the silicates which compose the normal rock. The pyrrhotite of the original magma, with the other metallic constituents, is supposed to have been concentrated in about the same way as in metallurgical furnaces, the copper and lead separate from the slag. The silicates are

supposed to have formed after this metallic segregation, and the pyrite, which was still fluid, filled the spaces between the crystals of silicate minerals and was itself congealed upon further lowering of temperature.

There are serious objections, however, to the theory that these ore masses in their present state are simple magmatic segregations. First of all the penetration of molten sulphides so far into the cooler country rock, as appears from Figures 11 and 12, is very difficult to explain in accordance with the laws of physics. Still more serious doubts are suggested by the condition of the ore-bearing rock bodies, as revealed by microscopic examination.

Cases occur, indeed, in which evidently corroded remnants of the normal silicates of the gabbros lie embedded in the mass of the ore as if they were

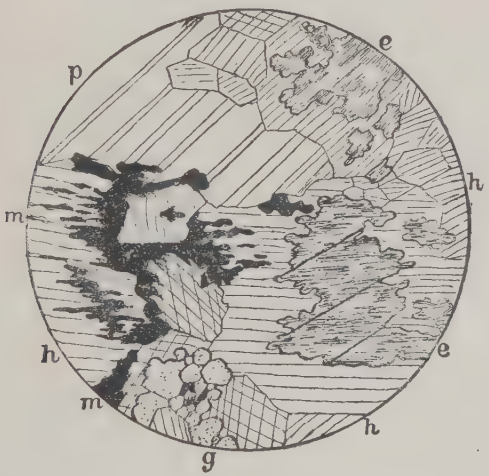

Fig. 15.—Ore-bearing norite from Solum Schurf, northwest of Erteli. (Enlarged 50 times.) e, enstatite; p, plagioclase; h, hornblende; g, garnet; m, magnetic pyrite.

earlier segregations which had been once more half melted down. In Figure 14 we give such an occurrence from Varallo, to be mentioned later on, and we admit that similar ones may be found in Norway, as in fact appears from Vogt's description. The corrosion of the plagioclase and diallage which we here observe, however, probably is due to solution by water, and this hypothesis is supported by the observation that in most cases the ore deposits are found in those parts of the gabbros that have been subjected to *very strong regional metamorphism,* and that in such cases the segregation of ore is shown to have taken place simultaneously with, or subsequent to, the regional metamorphism. The gabbro and norite patches against which the ores rest directly, or with which they are interspersed,

have almost always been more or less completely transformed into amphibolites and garnetiferous amphibolites. Figures 15 and 16 show this process not quite terminated.

Here we still have remnants of enstatite or diallage. In Figure 15, however, the ores prove to be younger than the two products of this later transformation, the green hornblende and the garnet. In Figure 16 the ore appears to have been segregated simultaneously with the garnets, and penetrates the older diallage only along fissures. *We believe, therefore, that the real and economically important concentration of the sulphides in the gabbro rocks took place only during the period of regional metamorphism and that it was effected by aqueous solution.* What was the original

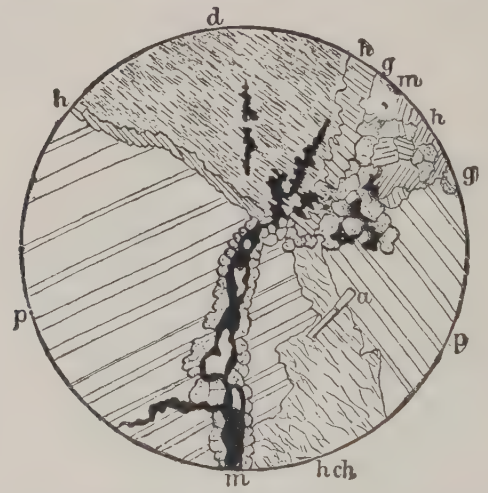

Fig. 16.—Ore-bearing gabbro from Erteli-Prästehaug. (Enlarged 50 times.)

d, diallage; p, plagioclase; a, apatite; h, hornblende; hch, chloritized hornblende; g, garnet; m, magnetic pyrite.

form and distribution of the metallic compounds in question in these eruptive rocks; whether they were very finely and uniformly disseminated pyrite particles, or chemical components of the bisilicates, cannot at present be decided. This will require a much more thorough petrographic investigation than any yet made.

The production of Norway attained its maximum in 1876, with 42,500 tons of ore containing 360 tons of nickel, the favorable conditions at that time permitting the smelting of ores with only 0.9 to 1.5% nickel. According to Vogt, 330,000 tons of nickel ore were produced between 1850 and 1893.

Analogous deposits occur in the neighboring kingdom of Sweden. The best known is Klefva in Smaland, whose nickel ores, by the way, show a

very small content in platinum, iridium, and rhodium.[1] To this class belong also Kusa in Dalarne, and Ruda in Ostergotland.

(b) The Nickel Ore Deposits of Varallo, Italy.

A second European occurrence of such deposits exists at Varallo[2] in Piedmont in the valley of Sesia. The gneisses and mica schists of the Monte Rosa area are traversed by an intrusive mass of norite about 20 kilometers long and 4 kilometers broad. The rock is an ordinary norite showing transitions to gabbro and to an olivine norite, but it has been largely altered by regional metamorphism into a hornblende rock like those of Norway. Large masses of magnetite found at the gneiss-gabbro contact in the Cevia and Sella Bassa mines were found to contain 4 to 5% of nickel and cobalt, and to hold pyrite and copper pyrite. The amount of nickel (including cobalt) in the ores formerly smelted in the Sesia and Scopello furnaces was 1.2 to 1.5%. The cobalt content is somewhat higher than in Norway, the ratio being 100 Ni: 50 Co: 40-50 Cu. The mines were worked from the end of the sixties to the end of the seventies. The Sesia mine belonged to the Saxon Blue Color Works.

From a genetic point of view what has been said of Norway is also true of Varallo. Compare also Figure 14.

(c) The Nickel Ore Deposits of Sudbury in Canada.

The Canadian nickel deposits are the most important deposits known of this kind. They have been described by numerous authors, but most of the papers deal with general and not the structural or genetic conditions[3].

The town of Sudbury is in northern Ontario on the line of the Canadian Pacific Railway, in the midst of an area formed mainly of Huronian schists,

[1] B. Santesson: 'Nikkdmalm fyndigheten vid Klefva.' *Geol. Fören Förh.*, Vol. IX, 107, 1887, pp. 66-73.

[2] A. W. Stelzner: 'Referat eines Vortrages,' *Berg u. Hütten Zeit.*, 1877, p. 87. M. Badoreaux: 'Mémoire sur la metallurgie du Nickel.' *Ann. d. Mines*, 1877, Mémoires, Vol. XII, p. 237. J. H. L. Vogt: 'Varallo in Piedmont,' *Zeit. f. Prak. Geol.*, 1893, p. 257.

[3] T. G. Bonney: 'Notes on a part of Huronian series of Sudbury,' etc., *Quart. Journ.* Geol. Soc., 1888, pp. 32-44. W. H. Merritt: 'The Minerals of Ontario.' *Trans.* Am. Inst. Min. Eng., 1889, Vol. XVII, p. 295. E. D. Peters: 'The Sudbury Ore-deposits,' *Trans.* Am. Inst. Min. Eng., 1890, Vol. XVIII. A. E. Barlow: 'On the Nickel and Copper Deposits of Sudbury.' *Ottawa Naturalist*, March 6, 1891. R. Bell: 'The Nickel and Copper Deposits of the Sudbury district.' *Bull.* Geol. Soc. Am., 1891, Vol. II, pp. 125-137. Also 'Report on the Sudbury mining district.' Geol. Survey of Canada, 1891. H. B. v. Foullon: 'Ueber einige Nickelerzvorkommen.' *Jahrb.* d. k. k. geol. Reichsanst. Vienna, 1892. J. H. L. Vogt: 'Bildung von Erzlagerstätten,' etc. *Zeit. f. Prak. Geol.*, 1893, pp. 128, 257. G. R. Mickle: 'The relation between Pyrrhotite, Gangue, and the accompanying Rocks of the Sudbury District.' *Sudbury Journal*, 1894. F. A. Adams: 'On the igneous origin of certain ore deposits.' Min. Assoc. Prov. of Quebec, Jan., 1894. F. L. Walker: *Quart. Journ.* Geol. Soc., Vol. LIII, No. 209, 1897, pp. 40-65. A. P. Coleman: *Report*, Bureau of Mines, Ontario, 1903, pp. 235-303. Also 1904, pp 192-224.

extending from the north shore of Lake Huron northeast to Lake Mistassini. According to Coleman, the nickel deposits are confined to the outer, basic edges and offshoots of a mass of igneous rock. A nearly continuous band of this rock, about 2 miles wide, forms a rude ellipse 36 miles long and 8 miles across, enclosing an area of tuffs, sandstones and slates of Cambrian or Upper Huronian age. Outside of this ellipse the rocks are of Laurentian or Lower Huronian age, a part of the so-called basal complex. The igneous rock presents a well defined gradation from norite (now largely altered to diorite) on its outer edge, to the quartz syenite and granite of the inner border. The norite (a hypersthene gabbro) contains scattered grains of bluish quartz and black mica. The ore deposits are of two types, (1) those "crowded into bay-like indentations in the adjacent rocks," (2) those "strung out along the narrow offshoots of the norite like sausages on a string, but with a long piece of string between them." The deposits are prevailingly lenticular, pinching out in both directions, and conforming to the general strike of the schists. The orebodies are much larger than those of the Scandinavian peninsula.

The Sudbury ores consist mainly of a mixture of pyrrhotite and chalcopyrite intimately associated with more or less country rock. The nickel occurs in the pyrrhotite, varying in amount from 2 to 5.5%, ordinarily 4 to 4.5%. The nickel occurs in the pyrrhotite as pentlandite $(Fe+Ni)S$. The copper pyrite is free from nickel. Occasionally polydymite (with 43% Ni) and millerite (64% Ni) occur in the ore, and at times patches of titaniferous magnetite have been observed. From the residue of weathered ores T. L. Sperry[1] isolated the interesting mineral sperrylite, a platinum arsenide, with traces of rhodium, palladium, and antimony. Furthermore, the Canadian matte, like that of Klefva and Ringerike[2], shows a small amount of platinum (0.25 to 0.50 oz. per ton) and palladium, as well as traces of iridium and osmium. Associated with the sperrylite some tinstone is found. Some ores contain small quantities of gold. The sperrylite occurs with the chalcopyrite in the unaltered sulphide ore.

According to A. McCharles[3] it has been found that the richest ores occur in the smaller offshoots of gabbro-diorite, and that the larger massives, with few exceptions, yield no workable ores at all. The gold, platinum, and the other accessory metals are contained not in the magnetic pyrite, but in the copper pyrite.

In their structure and in their relation to the country rock the Canadian deposits present a great similarity to those of Norway and Piedmont. The

[1] *Am. Jour. Sci.*, Vol. XXXVII, 1899.
[2] Vogt: 'Platingehalt in Norwegischen Nickelerz.' *Zeit. f. Prak. Geol.*, pp. 258-260.
[3] 'The Mineral Industry,' Vol. VII, 1899, p. 524.

Sudbury ores, moreover, contain peculiar breccias in which sharp-edged or rounded rock fragments lie imbedded in a paste consisting essentially of magnetic pyrite and some copper pyrite. The fragments consist of gabbro in highly varying stages of regional metamorphosis. Besides those which consist of a micro-breccia of minute diallage and plagioclase splinters, there are others which have been completely amphibolitized, or also show a distinct schistose structure. All are, moreover, more or less

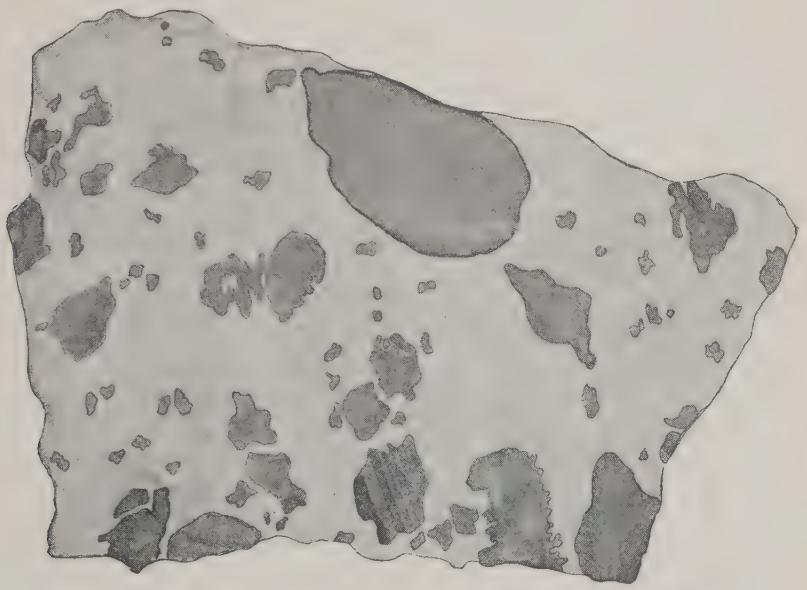

Fig. 17.—Polished ore specimen from Murray mine near Sudbury.
Two-thirds natural size. Gabbro fragments more or less transformed into hornblende schist in the midst of the ore mixture, which appears uniformly light colored.

impregnated with ore. Figure 17 shows an instance of such an occurrence, genetically interesting, from the Murray mine. Such specimens prove that the segregation of the magnetic pyrite and copper pyrite in their present condition *took place during or after the dynamo-metamorphosis of the gabbro rocks of that locality, and not by means of a magmatic differentiation.* This has been confirmed by the very careful detailed work of C. W. Dickson, who says that the evidence points to the secondary formation of the Sudbury orebodies as replacements along crushed and faulted zones[1].

[1] 'The Ore Deposits of Sudbury, Canada.' *Trans.* Am. Inst. Min. Eng., February, 1903.

The ore deposits of the Sudbury district are occasionally traversed by younger dikes of an olivine diabase, in which analysis has demonstrated the presence of NiO (0.027%) and CoO (0.005%) which was probably taken up secondarily (Walker).

The first deposit worked at Sudbury, the Copper Cliff mine, at first produced only copper, as indicated by the name. Later, toward the end of the eighties, the presence of a workable amount of nickel was found in the associated magnetic pyrite. This discovery in what had been waste ore at once caused the establishment of a very active nickel-ore mining industry. In the Sudbury district in 1903, a total of 220,937 tons of ore carrying 3.16% nickel were smelted, of which the greater portion came from the Creighton mine.

In the United States, the Lancaster Gap mine in Pennsylvania is, according to Kemp, the most important nickel deposit in the country. It seems to belong to the group just treated, being also situated at the boundary between a hornblende rock and crystalline schists.

Similar nickel ore deposits occur in other basic eruptive rocks altered by dynamo-metamorphism, especially in diabases.

(d) Deposits of Nickeliferous Pyrrhotite at Schweidrich near Schluckenau, in northeastern Bohemia, and at Sohland, in Saxony.

At Schweidrich the Lusatian granitite is traversed by a great west-northwest dike of a coarse-grained diabase, fine-grained at the borders, whose normal rock carries some primary hornblende and biotite besides the ordinary constituents. Near the northern wall of the dike this diabase is altered to a rock consisting mainly of secondary uralitic green hornblende, but at the same time more or less impregnated with nickeliferous magnetic pyrite and some iron pyrite. Under the microscope the segregation of the ores in many cases is distinctly seen to be younger than the formation of this secondary hornblende. The adjoining rock, a somewhat decomposed granite, is also impregnated with the same ores to a distance of more than one meter. Patches of compact ore occurring more rarely in the diabase contained, according to von Foullon[1], 7.8% nickel, 2.90% copper, 49.90% iron. No mining is going on there at present. At Aeusserst-Mittel-Sohland, north of Schluckenau, on the boundary between Saxony and Bohemia, the digging of a well in 1900 led to the discovery of an entirely analogous but much richer deposit. A dike 10 m. (33 ft.) thick of proterobase[2] rich in biotite traverses the Lusatian granite in a west-northwest

[1] H. B. v. Foullon: 'Ueber einige Nickelerzvorkommen.' *Jahrb.* k. k. geol. Reichanst, Vienna, 1892, p. 302. Compare O. Herrmann in 'Geol. Maps of Saxony,' 1897. Hinterhermdorf-Daubitz sheet, p. 19.

[2] A diabase rich in hornblende.

direction. Along the northern border, this rock has been found to be ore-bearing to a distance of about 700 m. (2,296 ft.) The ores consist of nickeliferous pyrrhotite, some copper pyrite and a little iron pyrite, forming either a mere impregnation, extending outward as much as half a meter into the granite, or as in the Herbergs Fund shaft, a compact ore up to 2.5 meters in thickness, dipping north at 75°, like the dike walls, and traceable for 20 meters along the strike, and yielding specimen ores with an average content of 5% of nickel and about 2% of copper. In the proterobase the sulphides are the last materials to crystallize, as in many cases fragments of pyroxene and of primary hornblende, which evidently have undergone corrosion, are surrounded by the pyrites. On the other hand, the pyrites are often seen in the midst of serpentinized pyroxenes, with a band of ore running parallel to their contour at a little distance from the edge. Very often, also, the pyrite is found in the form of thin lamellae wedged in between foliations of biotite.

In the hanging wall of the ore of the Fund shaft there are found in the proterobase very remarkable portions, quite rich in spinel and corundum. The rock also carries inclusions of sillimanite.

Immediately below the gossan of the deposit, which sometimes extends down as far as 10 meters, there has been found, as a secondary fissure filling, a rich blackish copper ore consisting essentially of copper glance. Recent investigations by R. Beck show that the ore was formed at the same time as the uraltic hornblende and the ore is regarded as a deposit from thermal waters rising as an aftermath of the diabase eruption[1].

The nickel deposits of Horbach in the Black Forest, concerning which but little scientific information is available, possibly should be included here, as also the nickel ore of the Hilfe Gottes mine, near Nanzenbach, in the Weyerheck, 4 miles (7 km.) northeast of Dillenburg in Nassau[2], where irregular stocklike masses of iron pyrite, copper pyrite, and nickel arsenide are associated with a greatly altered rock of the diabase group.

(e) Arsenious Nickel Ores in the Serpentine of Malaga, Spain.

While the widely distributed secondary nickel ores found in serpentines are treated under another heading, the Malaga deposits of arsenical nickel are most naturally included here.

In the Archean strata to the west of that town there are serpentine rocks which have resulted from the alteration of an olivine pyroxene rock, and from olivine norite, as well as from olivine rock (dunites) proper.

[1] *Zeit. f. Prak. Geol.*, Feb., 1904. *The Engineering and Mining Journal*, 1904, Vol. LXXVII, p. 363.

[2] H. Laspeyres: 'Das Vorkommen,' etc. *Verhandl.* d. Naturh. Ver zu Bonn, 1893, Vol. 50, Plate IV, and Pt. II, p. 451.

According to F. Gilman[1] the upper portions of these serpentines were found to contain secondary nickel ores of the pimelite and garnierite type, with 1 to 20% of nickel. At greater depth nickel arsenide (niccolite) made its appearance in the following manner:

1. Fine chromite grains are cemented by niccolite (see Figures 18 and 19); the bronze mosaic ore exists in nests and veins in fresh serpentine, and contains 5 to 20% of nickel.

2. Crystals of a dark greenish brown augite up to 1 centimeter long are cemented by niccolite and chrome iron.

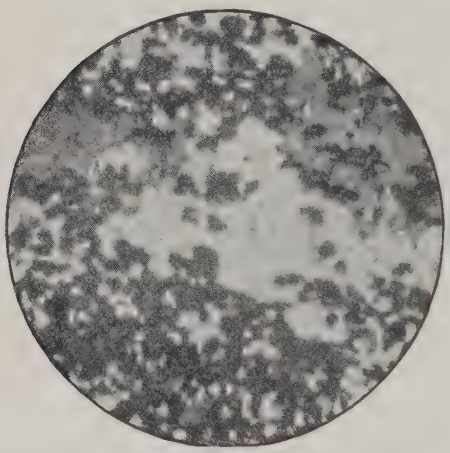

Fig. 18.—Chromite (dark) with niccolite (bright) from Primera mine; with light from above. (Enlarged 27 times.)

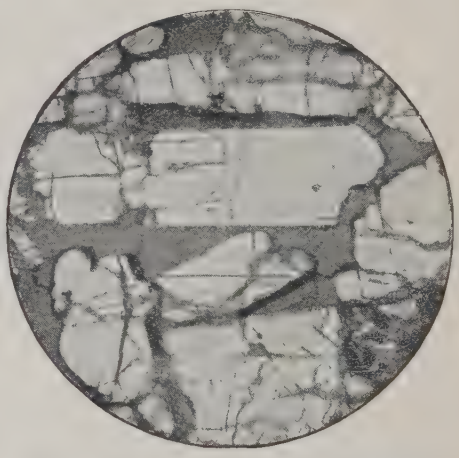

Fig. 19.—Augite crystals (bright) cemented by niccolite (dark); with incident and also transmitted light. (Enlarged 10 times.)

3. Masses of unaltered norite sometimes as large as an ostrich egg occur in the serpentine, which besides its main ingredients (plagioclase and rhombic pyroxene) also contains interspersed granules of niccolite and chromite and chrome iron ore. Sometimes the niccolite forms a regular groundmass about the silicate crystals; more rarely it has been secreted, together with chromite, in streaks and bands.

At times iron pyrite and copper pyrite are found in the ores. The above named author considers the niccolite (Ni As) as a product of magmatic differentiation. The example suggests that fresher rocks with arsenide nickel ore also may be expected, as other garnierite deposits are worked to a greater depth.

[1] F. Gilman: 'Notes on the Ore Deposits of the Malaga Serpentines.' Inst. Min. and Metal., London, January, 1896.

2. *The Copper Ore Deposits in the Serpentines of Italy.*

According to B. Lotti[1] the serpentines of Tuscany and Liguria almost all contain some copper sulphide, some of the serpentine masses containing deposits known for many centuries. According to Lotti three rock types are recognized in the strongly serpentinized rocks of this region: altered lherzoliths (olivine rock proper), decomposed olivine gabbros, and transformed olivine diabases (called by others melaphyres). These rocks form lenticular or stocklike intrusions in Eocene strata, occurring usually in an orderly sequence in which the former lherzolith is below, and the diabase on top. It is probable that there were two intrusions, first one of lherzolith, next a second whose magma congealed in the form of gabbro at the bottom, and as diabase at the top. In the middle member of this series, the gabbro, the following ores are found: pyrite, copper pyrite, bornite, copper glance, rarely also blende and galena, all in finely disseminated particles. At some points, however, these ores also occur as globular masses or large lumps, about which the decomposition of the country rock is apt to be particularly pronounced. Authors are at present fairly well agreed that the finely distributed ores are original segregations of the magma. On the other hand, in regard to the spherical masses and lumps the views are as yet wide apart. As described later the character and occurrence of such ore masses indicate their origin by secondary concentration of the sulphidic ores into such masses. Exact proof seems as yet impracticable. The best authority on these formations, B. Lotti, now regards them as original segregations. As a special example for this type of deposits we will select the famous locality of Monte Catini.

The Monte Catini Copper Deposit.

Between the Maremna Marshes and the Apennines in Tuscany there extends a hilly country whose numerous wooded summits of eruptive rock overtop the gently sloping areas of Tertiary marls. The mine of Caporciano, near Monte Catini, situated on one of these hills, is said to have been founded by the ancient Etruscans, and in fact the ancient Etruscan town of Felathri, now the walled town of Volterra, lies near the mine. The igneous rocks are intruded in the Tertiary strata in the form of a great lens or laccolith. Above the Eocene marls and limestones, which form the floor of the intrusion, is a strongly serpentinized olivine gabbro forming the base of the eruptive series. This occurs as a stock, which in cross-section is three-armed, and enveloped by the olivine diabases (melaphyres) of Monte Massi, and in part appears intercalated between the diabase and the sedimentary

[1] B. Lotti: 'La genèse des gisements cuprifères des depôts ophiolitiques tertiaires d l'Italié,' *Mem.* Geol. Soc. Belgium, Vol. III, 1899.

strata. A longitudinal layer of diabase divides the gabbro into two approximately parallel parts known as the *filone rosso* and the *filone blanco,* both wedging out downward at the point where the underlying sedimentary rocks begin (Figure 20). The serpentine stock is bounded on both sides by slickensides and its central portion is, moreover, exceedingly fissured and crushed to a fine breccia, probably as a result of the increase of volume on serpentinization. Certain parts of the stock resemble a breccia whose fragments are in part serpentinized olivine gabbro, in part decomposed olivine diabase (Fig. 21 and 22)[1]. In this breccia are also found concretionary secretions of quartz and chalcedony.

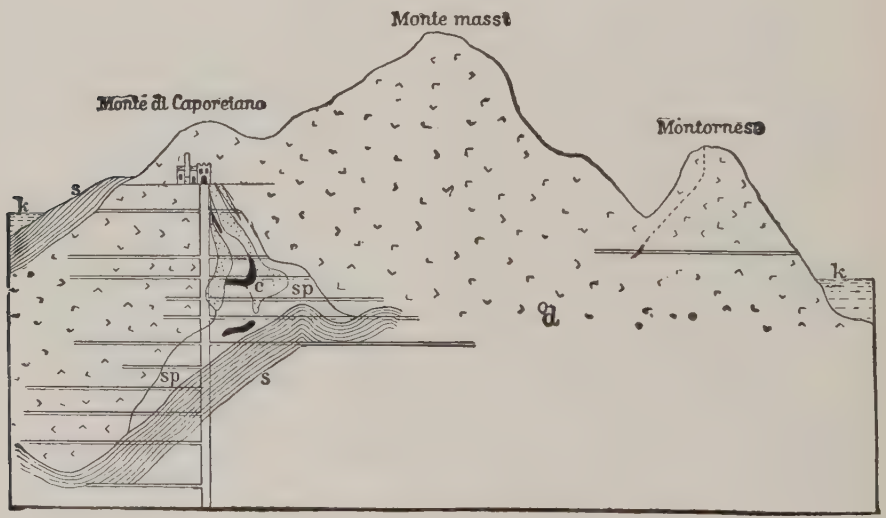

Fig. 20.—General profile through the deposit of Monte Catini from south-southwest to north-northeast. (Fuchs and De Launay.)

s, clay slates and calcareous marls of the Eocene; d, olivine diabase; sp. serpentine, c, conglomerate, the black parts representing ore; k, younger marls and limestones.

The ores form bodies of irregular shape and varying size, which are quite irregularly distributed in the serpentine, or occur at its contact with the above mentioned breccia; some of them are quite isolated (Figure 21); others are connected by ore stringers (Figure 22). The isolated ones attain a diameter of several meters, while occasional compact masses of copper

[1] G. vom Rath: 'Ein Besuch der Kupfergrube Monte Catini,' etc. *Zeit. d. D Geol.*, 1865, pp. 277-310. E. Reyer: 'Aus Toscana.' Vienna, 1884. B. Lotti: 'La miniera cuprifera di Montecatini.' *Boll.* Com. Geol., XV, 1884. A. Schneider: 'La miniera di Montecatini.' Append. *Riv. Mineraria del* 1889. B. Lotti: 'Considerazioni sintetiche sulla orografia e sulla geologia della Catena Metallifera in Toscana,' *Boll.* Com. Geol., Vol. XXIII, 1892.

pyrite have been met, having a volume of 6 to 10 cubic meters. The majority are rounded bodies coated with a brilliantly polished serpentine-like crust. This crust often shows cracks and streaks which record a movement in the soft country rock. Such streaks lead often to other ore-bodies.

In the main, these ore boulders or lumps consist of copper pyrite. Fre-

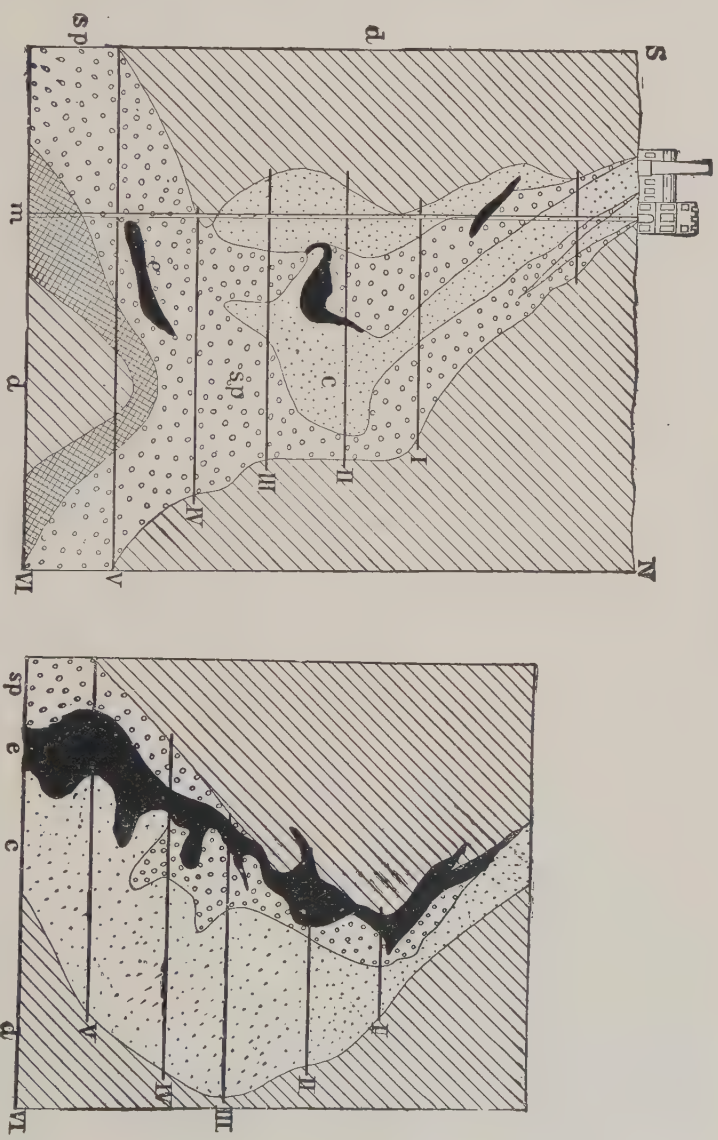

Fig. 21 and 22.—Detailed cross-sections through the deposit of Monte Catini. (G. vom Rath.)
m, calcareous marl; d, olivine diabase; sp, serpentine; c, conglomerate of serpentine and diabase; e, orebodies.

quently, but not always, they show a concentric structure, with a core of copper pyrite surrounded by a shell of bornite, often covered by an outer crust of pyrite or of copper glance and native copper. Moreover, the serpentine which surrounds the rounded ore masses contains so much ore in a finely divided condition that it is worked. The ores of Monte Catini are classed as rich ores when the copper content is as high as 7%; as lean ores when it is but 1.25 to 1.50%. The irregular distribution of the ore masses, and their irregular form, together with the absence of continuous lodes or beds, has rendered mining very difficult; nevertheless, it had its periods of great prosperity. Some 400 meters east of the main stock and at a depth of 150 to 200 meters there is a second bed running east-southeast, the so-called Demetrio lode, with copper pyrite, bornite and copper glance.

According to G. vom Rath the orebodies of Monte Catini were formed by a concentration of the metallic sulphides of the original rock during their serpentinization. E. Reyer considers the deposit as a lode that subsequently had been strongly dislocated. B. Lotti, as already stated, considers the lumps of ore as original segregations. The mining industry of Monte Catini, abandoned during the Middle Ages, was resumed in the 15th century, again interrupted, and once more resumed in 1828. It attained its maximum of 3,000 tons of ore in 1860.

Similar, though less important copper ore deposits associated with serpentine are known on the island of Corsica (Ponte Alle Lecchia), in Servia[1], in Greece (Epidauros) and in Northern Norway (Hatfjelddal), and in Cuba[2].

The deposit of Cava Grande on the Temperino lode, in the Campiglia Marittima, which by some is placed in this category, will, in the present work, be treated under contact ore deposits.

3. *The Copper Ores of Ookiep in Little Namaqualand.*

According to A. Schenk[3], the copper ore deposits of Ookiep, formerly considered as lodes, are magmatic segregations in a rock consisting almost entirely of plagioclase with but little biotite, hornblende and augite, forming stocklike intrusion in gneiss. The ores contain bornite, chalcopyrite, some copper glance, pyrrhotite and molybdenite. The mines have yielded as high as 30,000 tons of ore a year, with an average content of 27.5% copper.

[1] R. Beck and W. Baron v. Fircks: 'Die Kupfererzlagerstätten von Rebelj und Wis in Servia.' *Zeit. f. Prak. Geol.*, 1901, p. 321.

[2] W. H. Weed: *Engineering and Mining Journal*, Feb. 3, 1905.

[3] *Engineering and Mining Journal*, Feb. 10, 1905. See also *Zeit.* d. D. G. G., 1902, Vol. LIII, pt. 4, p. 64.

SECTION II.

BEDDED ORE DEPOSITS.

Ore deposits of direct sedimentary origin, together with deposits of similar form resulting from impregnation and metasomatic replacement of sedimentary beds, are grouped together as bedded ore deposits.

General Features of Bedded Deposits.

According to the generally accepted definition of B. von Cotta[1], "Accumulations of ore, which lie parallel to the stratification or foliation of the rock enclosing them, consequently forming one or more subordinate layers between any stratified or foliated (schistose) rock, are called ore beds." We may further distinguish between *interbedded* deposits which are overlain by other strata and *surficial* deposits when there are no overlying beds, as, for example, a bog iron ore bed. If the stratified deposits are syngenetic, as has been assumed, the further tacit supposition follows that the ore beds and ore strata were deposited but little later than the underlying rock and but little earlier than their overlying bed. In the case of the metasomatic ore beds and impregnated layers this assumption refers only to the original layer, whose substance was subsequently displaced by ore or whose interspaces were subsequently filled by ore; they are then not true beds but bedded veins.

Like any other stratum of sedimentary rock, an ore bed may contain and be recognized by certain fossils (diagnostic fossils) which are usually mineralized. Thus, a characteristic fossil of the Oolitic iron ore beds of the Brown Jura is an ammonite (*Harpoceras Murchisonae*); and for the Eocene iron ore measures of upper Bavaria it is a sea urchin (*Conoclypeus Conoideus*).

Sometimes it is very difficult to distinguish the true stratified beds from bedded veins (see later on). The stratified beds are distinguished from

[1] B. von Cotta: 'Die Lehre von den Erzlagerstätten.' Freiberg, 1859, Vol. I, p. 85. Prime's translation, New York, 1870, p. 17.

the stratiform or bedded *lodes* mainly by negative marks; their boundaries above and below are for the most part not so sharp. They never cause displacements and never cut across another bed or a lode. They never form veinlike offshoots entering into the adjacent rocks, and do not enclose fragments of the country rock. In folded regions the beds follow all the windings of the surrounding strata.

Formerly ore beds when tilted at a high angle were considered as lodes, even in mining legislation, because mining such a deposit is like that of a lode.

The definition given for stratiform deposits involves, furthermore, a considerable extension of the deposit in length and breadth, combined with a relatively small thickness. The known exceptions to this law, such as the so-called ore 'pods' (Erzlineale) of the Norwegian pyrite deposits (see description) are, in point of fact, examples which are not true beds or are at least of doubtful genesis; as for instance, at the Mug mine, near Röros, in Norway, there is a low-dipping bed of phyllite and pyrite, which was found to be ten times longer than it was wide, the length coinciding with the dip.

It is customary in many places to apply the name 'seams' to those stratified ores which have a great horizontal distribution with a small and nearly constant thickness. The name 'lenticular' beds (*lager*) has been given to those which have a relatively small horizontal distribution with a relatively great thickness, and which may show great variation in thickness. As typical examples of these two extremes we may mention the copper shale measure of the German Zechstein formation, which maintains its thickness of 0.5 meter over about 4 square miles, though it does not everywhere pay; and the Norwegian pyrite beds, whose thickness varies between 0 and 26 meters and which have slight areal extent. Some writers call the *older* deposits *beds* (*lager*), the *younger* ones *seams* (*flötze*). In any case the distinction is not a sharp one.

The thickness of bedded deposits is never very great; the extreme thickness of the big iron ore lens of the Sjustjernberg, near Grängesberg, in Sweden, amounting to 90 meters, probably represents the greatest thickness known, and this really includes some intervening strata which are either barren or poor in ore.

Where the thickness of the orebody decreases until it disappears the ore bed is said to wedge out (as at *a* in Figure 23), or it may merely become much constricted with a narrow band of ore still remaining (at *b*), which increases in thickness some distance away, forming another orebody. This is termed "enlargement." After wedging out, a clay-filled or even entirely

empty joint fissure sometimes indicates the horizon, and the miner must carefully follow this fissure if he wishes to find further orebodies.

Frequently this alternate wedging out and thickening cuts up a deposit into series of lenticular beds belonging to a common horizon, which may be termed a *chain*[1] (lagerzug) (Figure 24). The German term is also applied to a succession of beds which belong not exactly but at least approximately to the same horizon. An example of this is found in the series of 'minette' beds or measures of the Moselle region occurring in the *Harpoceras Murchisonae* formation; also the double series of magnetic iron ore deposits at Gellivare.

A bed which has a comparatively great thickness, but wedges out rapidly in all directions, is called a lens (see Figure 25). As examples we may mention many magnetic iron ore lenses in the crystalline schists. The flat, disc-shaped spherosiderite concretions in clay slates of the Carboniferous or

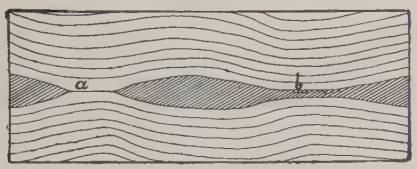

Fig. 23.—Wedging out (*a*) and constriction (*b*) of bed.

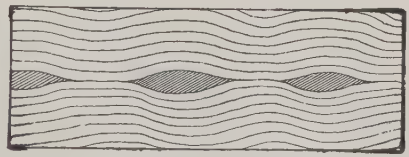

Fig. 24.—Series of ore lenses of bedded deposit.

of the Jurassic are miniature lenses, which are also called 'buttons' in some localities. Similar spheroidal formations constitute the 'muggeln' of the Austrian miners.

If the lens has an irregular outline it passes, according to its dimensions, into a bunch, pocket, or stock (Fig. 26). These irregular forms of deposit are less common in the stratified deposits, proper, than in the metasomatic orebodies, such as masses of spathic ironstone, while in still other cases they are the result of orographic pressure. One may further subdivide such deposits into flat and upright stocks, according as their longitudinal axis is horizontal or vertical.

Very frequently a stratified orebody contains barren or at least poor unworkable layers, intercalated parallel to the stratification. These are called 'partings' (zwischenmittel), or 'stone-band' (bergemittel), as, for example, the partings of gray gneiss in the iron orebodies of Sweden.

[1] *i. e.*, the lenses are the links of a chain of orebodies.

In certain cases a bed of ore does not terminate by simple wedging out, but by the intervention of thin bands of barren rock, which increase in number or thickness. In other cases there is simply a gradual increase in the barren constituents of the normal ore. In the latter case the bed is said to become *impoverished*. This is particularly frequent in metasomatic replacements and impregnations. Thus the pyrite and blende deposits near Schwarzenberg in the Erzgebirge pass very gradually along the strike into barren amphibole-garnet rocks.

The part of an orebody intersected by the earth's surface is called the outcrop. A distinction is made between a true or exposed outcrop and a blind or covered outcrop. In the latter case the ore bed is concealed by unconformable débris or deposits of alluvial strata.

To both the miner and the mining geologist the form of the outcrop of a bed is of much importance, since it indicates the direction for further exploitation.

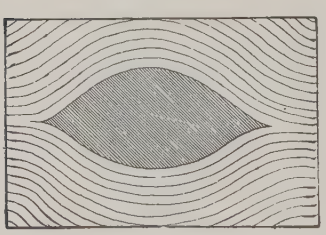

Fig. 25.—An ore lens.

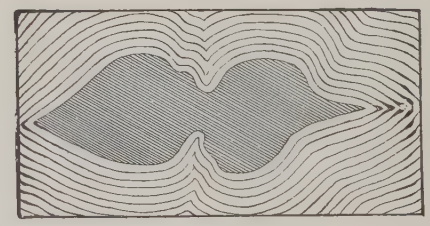

Fig. 26.—An ore stock.

The shape and extent of the outcrop depends on (1) the inclination of the bed, and (2) on the relief of the ground. A practiced eye will be able, from the form of the outcrop shown on an accurate geologic map, to infer with certainty the direction and angle of dip, and conversely, those factors will have to be known in order to plot a bed correctly on a map. According to K. Keilhack[1], the following typical cases occur.

1. Horizontal strata form lenticular outcrops running parallel with the contour lines of a good map. A horizontal bed outcropping on the slope of a mountain shows in a gorge as a crescent-shaped outcrop or bifurcated figure, in which one branch is seen on one side and the other branch on the opposite side of a valley. In a valley whose slopes are furrowed by lateral gulleys a horizontal bed will form a sinuous outcrop (Fig. 27-29).

[1] K. Keilhack: 'Lehrbuch der praktischen Geologie.' Stuttgart, 1896, p. 210, *et seq.*

2. Vertical beds give, under all circumstances, straight outcrops which run, undeviating, over mountain and valley, and at the same time represent the direction of strike (Fig. 30).

3. A more complicated form is assumed by an outcrop of inclined strata. In this case it is first to be noted that in general the boundary line or out-

Fig. 27-29.—Behavior of the outcrops of horizontal strata in diverse types of topography.

crop of the bed runs parallel to the contour lines only when the strike of the bed agrees with the direction of the contour.

On the contrary, if the inclined lines of the outcrop run at right angles to a valley they form in it an acute angle; the water flows into this V when the dip of the bed is down the valley and steeper than the slope of its bottom; in all other cases it flows out of the Λ (Fig. 31 and 32). If out-

Fig. 30.—Course of the outcrop of a vertical bed in irregular topography.

crops of inclined strata run across a mountain ridge, they form arches which open toward the foot of the mountain when the dip runs in that direction and is steeper than that of the slope. In the opposite case the arches open

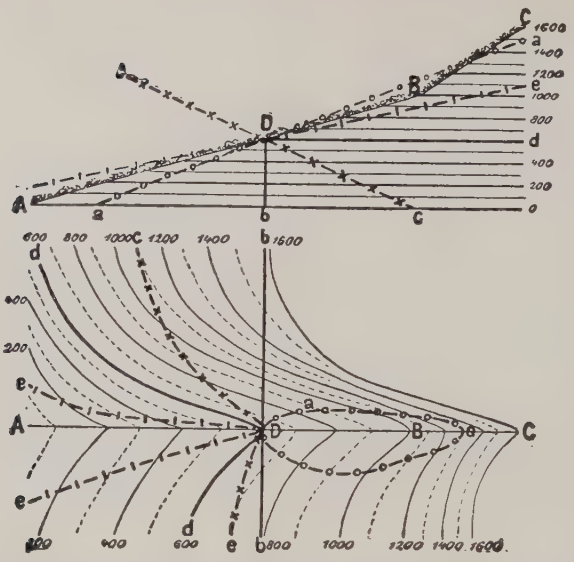

Fig. 31-32.—Outcrop of differently inclined beds in a valley. (K. Keilhack.)

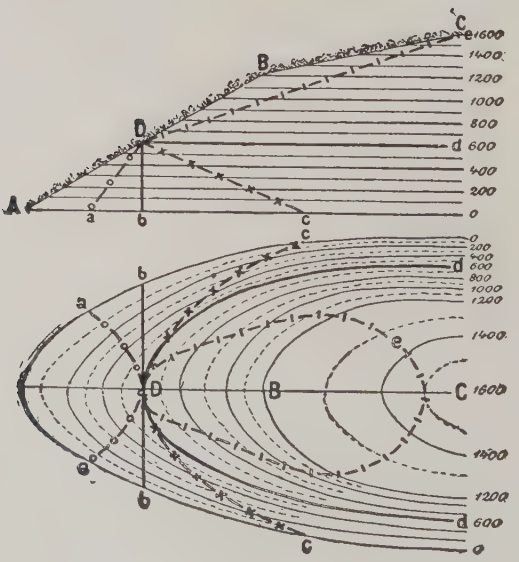

Fig. 33-34.—Outcrops of differently inclined beds on a ridge. (K. Keilhack.)

toward the summit of the mountain or even form closed figures. (Fig. 33 and 34.)

In searching for ore beds, or for any other kind of beds, one should, in prospecting by tunneling, boring, or by sinking shafts, run as nearly as possible at *right angles to the general strike* of the stratified rocks of the region. If the beds form an isolated exposure, the first thing to be done is to obtain an exact section of the local series of strata to which it belongs, identifying individual beds by means of characteristic fossils or locating certain prominent strata by their particular lithological character, as the case may be. This section afterward often will be of the greatest practical use when the miner encounters dislocations in working the bed.

Disturbances or dislocations of strata show:

(1) In a bending and folding of the beds without interruption of their continuity.

(2) In a breaking and disruption of the strata, by flexure, pressure, thrusts, etc., accompanied by the formation of fissures or cracks. If displacements occur along these fissures we speak of them as *faults.*

1. Flexures.

In describing the various forms produced by folding we may begin with the closed syncline (Fig. 35). In this case the bed forms a 'canoe' or bowl, dipping downward from all sides to the bottom of the basin (center or axis of syncline). The structure is concentric and the outcrops form circles

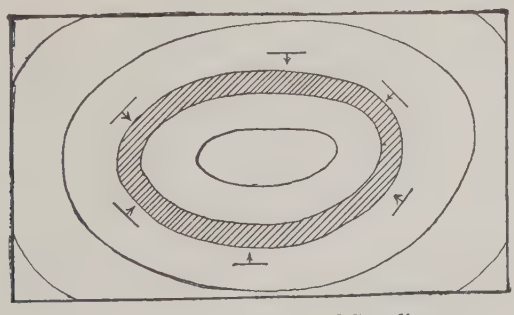

Fig. 35.—Plan of a Closed Syncline.

or ellipses. Thus, the Mansfeld copper shale, aside from small deviations, forms a trough 4 k. (2.4 miles) wide and open only toward the southeast.

The opposite of a basin or closed trough whose concavity is directed downward is the dome or closed saddle. The two forms are contrasted as synclines (trough) and anticlines (saddle). When the axis of a syncline or

anticline has a certain length and is cut off at both ends by erosion or dislocation, *open synclines* and *open anticlines* result. (Fig. 36.)

Every open form of this kind consists of two limbs or flanks connected at the axis of the syncline or the axis of the anticline. The strike of the strata in these cases is not quaquaversal—*i. e.*, encircling—but rectilinear.

The axis of a fold may be horizontal or be inclined toward the horizon; in the latter case its inclination is called its pitch.

The transition from one limb of a fold to another is ordinarily effected by a gradual curve (open fold), more rarely by an abrupt, sharp angle (closed fold) or by a repeated plaiting of minor plications. In large synclines, lesser flexures may produce subsidiary synclines and anticlines. All these phenomena are well exhibited in the main bed of the Carboniferous spathic ironstone measures of Westphalia, and the anthracite coal beds of Pennsylvania.

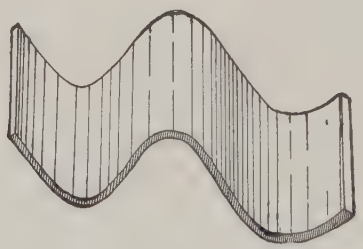

Fig 36.—Open syncline and open anticline, together forming a flat fold.

Both in anticlinal and synclinal folds a strong horizontal thrust may cause a complete inversion of the strata. Examples may be found in the inverted, that is to say, reversed, succession of strata shown in the Lower Silurian iron ore deposits of the Steinach valley in the Franconian forest, and the inverted pyrite beds of Rammelsberg.

Anticlines whose upper parts have been removed by erosion and denudation are called aerial arches.

An anticline and a syncline that have been brought close together by horizontal thrust form a *recumbent fold* with a middle limb and two side limbs.

2. Displacements. (Thrust Faults.)

Sometimes the limbs of an overturned fold have been subjected to such intense thrust or squeezing that they have finally yielded and been torn

apart along a gliding plane. The discussion of such thrusts, or fold faults, is reserved for the general discussion of faulting, which, for various reasons, is not treated in this place, but later in connection with mineral veins.

Distribution of Ore Within an Ore Bed.

When stratified deposits consist not of solid ore, but of ore mixed with barren, non-metallic minerals in one stratum, the distribution of the ore is an important factor. The determination of the distribution of the ore is especially important in those stratified deposits formed by impregnation, because in such cases its occurrence is apt to be very irregular, as for instance, in the gold-bearing conglomerates of South Africa. The particles of ore interspersed in the barren matrix may be of dust-like fineness, as in the Mansfeld copper shale; they may form small nodules, as in the galena-bearing variegated sandstones of Commern, or finally they may form larger concretions, as in many spherosiderite deposits.

If the rock in which the ore occurs in very fine particles or granules is a crystalline schist, it is customary to call the deposit in question a *fahlband*. The word was first used for the schist zones of Kongsberg, in Norway, containing iron pyrite, copper pyrite, magnetic pyrite, etc., in very fine particles, and though the beds are not sufficiently rich to be workable themselves, they are important because they enrich the silver veins which cut through them. German miners call these zones fahlbands because in the outcrop where the pyrites have been decomposed, the rock is gray. Typical fahlbands are found in the glance-cobalt deposits of Skuterud.

Structure of Bedded Ore Deposits.

Like all stratified formations, bedded ore deposits quite frequently appear to be built up of different strata, as for example, with many iron ore deposits. If the stratum consists of layers of different mineralogic composition the true bedded deposits fail to show a symmetrical disposition of duplicate bands, in cross-section. This is an essential mark by which to distinguish them from the true veins which they often closely resemble. As a rule the true bedded deposits also lack druse cavities (vugs) extending parallel to the stratification. On the other hand, certain bedded ore deposits possess a feature lacking in lodes: they carry fossils or pebbles of true fluviatile or littoral origin.

Mineral Contents of Stratified Deposits.

The only ore deposits thus far positively demonstrated to be of actual

sedimentary origin (at least on a large scale) are those of iron and manganese, the ores assumed to be of this nature being described under the name of the metal. An important feature of ore beds is the presence of a matrix of certain non-metallic minerals which are entirely or almost wholly lacking in veins, viz.: green hornblende, light green pyroxene, pistazite and garnet. The primary ore content of a bed is, as a rule, apt to be much more constant than in a vein, and hence in upturned strata the value is not apt to change with increasing depth. The case may be different with epigenetic ore beds; for example, the beds of Meggen on the Lenne consist in one part of barite, in another part of iron pyrite. An exception is also found in beds of metasomatic origin, such as the Schwarzenberg beds, which in one place may be developed as copper, in another as a blende deposit.

As regards the differences in mineral content by reason of superficial alteration at and beneath the outcrop, the same results occur with strata as with vein outcrops, as will be shown later. Both have a gossan whose secondary minerals depend entirely on the primary contents. A bed of iron pyrite carries a gossan of brown hematite; a bed of galena forms a gossan with much cerussite, etc.

Classification of Sedimentary Ore Deposits.

The primary ore deposits of this group may be divided into two classes: (a) Those in which the ore bed and its enclosing strata have undergone little or no change since their deposition (purely sedimentary deposits), and (b) those in which both ore and country rock have passed through a recrystallization or some other important structural transformation (metamorphic ore deposits). Typical examples of the first group are the lacustrine iron ores and most of the Oolitic iron ores; for the second group the Archean iron ores. In many cases, however, it is not possible to draw a sharp boundary between them; in general, the older the deposit the more likely it is to be metamorphosed. Hence the primary ore deposits of this kind will be arranged by geologic age, progressing from the older to the younger, and subdividing all into different groups according to the respectively predominant metals.

We include in sedimentary ore deposits those stratiform masses which contain the ores finely distributed, in the form of dust, granules, scales, or nodules, provided the assumption is justified that this ore content interspersed in particles was deposited simultaneously with the barren constituents. Here, too, a subsequent metamorphism has often occurred, as for example, in the specular iron schists. It will be difficult in individual

cases to distinguish sedimentary ores whose finely disseminated metallic particles are of simultaneous origin, from those strata whose ores are the result of a secondary impregnation. The Mansfield copper shale, for example, is placed by various authors now in one group, now in the other. The discrimination becomes even more difficult when such secondarily impregnated sediments as the cobalt fahlbands of Modum have undergone a subsequent metamorphism which has effaced the original character of the ore.

In a rigorously consistent classification we should have to add to the two categories just discussed, according to G. Gurich[1], a third category, a

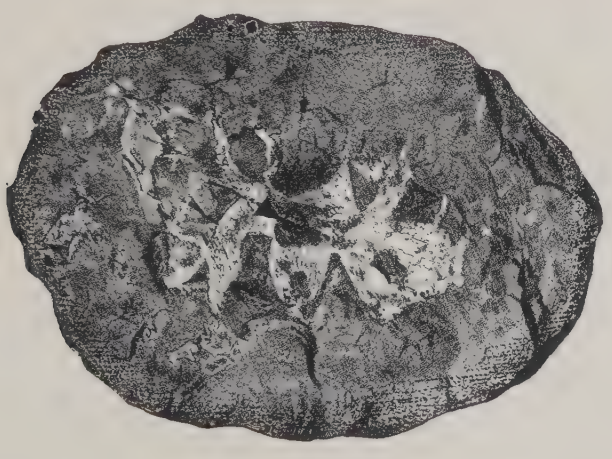

Fig. 37.—Lens of spherosiderite from the clay slate of Bocksberg, split longitudinally. (One-fourth natural size.)

diagenetic group of stratified ore deposits, namely, those deposits in which the concentration of the ore took place in the muddy sediment of a water-laid deposit before it was hardened into rock, as for example, in the slate clays with kidneys of spherosiderite. A good instance of this process is seen in the clay ironstone lenses up to 1.5 feet across in size in the Lower Coal measures of western Pennsylvania. The concretions in the roofing slate of Bocksberg, Germany, show an outer layer impregnated with pyrite crystals, whose arrangement, as will appear by reference to Fig. 37, shows the stratification of the clay slate displaced by the spherosiderite. In the

[1] 'Sitz.-Ber. d. Schles. Ges. f. vaterl. Kultur.' February, 1899.

center is seen a network of quartz stringers. However, for the sake of simplicity we include this small group with the ore deposits regarded as normal sediments. We will now proceed to the special classification and sketching of the most important groups, laying special stress on certain examples.

1. SEDIMENTARY IRON ORE DEPOSITS.

(A) Sedimentary Iron Ores of the Crystalline Schists.

(a) Crystalline Schists with Disseminated Iron Ores.

Magnetite and hematite occur as accessory constituents disseminated through portions of crystalline schists of almost all known areas. At times, however, they form the principal constituent of quartzites, mica schists, and similar rocks, and thus attain importance as ore deposits. The following occurrences illustrate this class:

Specular Hematite Schists.

Specular hematite schists are granular schistose mixtures of micaceous hematite and quartz. They are known to occur at several localities in Germany[1], viz.: Soonwald and Marmarosch (Cotta), in many parts of Norway, and particularly in the ancient schistose rocks of Brazil[2]. In the latter country at Itabira and Antonio Pereira they form a great series of strata intercalated between clay slates and itacolumites. They also occur in South Carolina[3]. In both countries they are associated with gold deposits.

Itabirite.

Itabirite is a granular schistose mixture of quartz with hematite and magnetite, which occurs at Itabira, Villarica, and other localities in Brazil, associated with specular hematite schists. It also occurs at Sutton in Canada, included in metamorphosed Silurian strata. In Brazil this rock also contains gold, and Hussak[4] considers itabirite as the matrix of the waterworn specimens of cinnabar found in the alluvial 'Cascalho' of

[1] Noggerath, in Karsten's *Archiv.*, Vol. XVI, 1842, p. 515.
[2] v. Eschwege: 'Beiträge zur Gebirgskunde Brasiliens.' Berlin, 1832.
[3] Lieber: *Rep.* Geol. Surv. S. Car., 1856.
[4] Hussak: *Zeit. f. Prak. Geol.*, 1897, p. 65.

Tripuhy. The same rock occurs in South Carolina associated with mica schist, itacolumite and talcose schist rich in magnetite grains, the so-called catawbirites. Here, too, gold deposits are known in this group. These examples are economically of less importance than certain Norwegian deposits of which a fuller description is given.

The Iron Ore Field of Naeverhaugen.

This district, situated on the west coast of Norway, 24 miles (40 kms.) east-northeast of the town of Bodö, is, according to A. W. Stelzner[1] and J H. L. Vogt[2], a region of metamorphosed Paleozoic rocks consisting of garnetiferous mica schists, quartz schists, amphibole schists, mica gneisses, pyroxene gneisses, epidote schists, and granular crystalline limestones. In certain layers both the mica and the quartz-schists carry numerous interspersed flakes of specular hematite, with subordinate granules of magnetite. Thin, highly ferriferous layers alternate with barren layers. These finely banded layers of ore attain a thickness of 16 to 22 ft. (5 to 7 m.), sometimes 25 to 30 ft. (8 to 9 m.); greater thicknesses, up to 50 ft. (16 m.), occur, but are due to folding. The foliated schists contain, moreover, layers of rich ore sometimes 0.3 feet to 0.6 ft. (10 to 20 cm.) rarely a foot thick, in which the amount of iron, ordinarily about 50%, may rise to 58%, with a phosphoric acid content of 0.2 to 0.4%. The barren layers of the banded ores consist of quartz, with some hornblende, pyroxene, epidote, and garnet. Accordingly these ores approach the Swedish Striberg type.

These occurrences form a transition from the deposits of disseminated ore to the beds of the compact iron ore in the crystalline schists. This last named class includes a variety of ores. Those of spathic ore will be described first, then those of magnetite and iron glance:

Compact Iron Ore Beds of the Crystalline Schists.

The Carbonate Iron Ore Beds of the Crystalline Schists.

Owing to the ready solubility of iron carbonate where it is associated with limestone or dolomite, and the frequent migration of material, the original sedimentary character of all the deposits of this class has been greatly obscured by secondary metasomatic processes. This is particularly true of the most important example, described below.

[1] A. W. Stelzner: 'Das Eisenerzfeld von Naeverhaugen.' Berlin, 1891.

[2] J. H. L. Vogt: 'Salten og Ranen.' Christiania, 1891. Cited in *Zeit. f. Prak. Geol.*, 1894, p. 30.

1. *The Iron Ore Deposits of Huttenberg, in Carinthia*[1].

In the eastern Alps crystalline schists and granites make up the central east to west range of the system. To the north and south the rocks of other ages occur as steep-dipping and often dislocated strata lying against this zone; first a low area of essentially Paleozoic rocks, then the Mesozoic limestone of the steep and high ranges of the Alps. The spathic ironstone beds of Huttenberg, northeast of Klagenfurt, belong to the central zone. The beds and the associated granular crystalline limestones form a series of strata which extend from the vicinity of Friedsach on the Olsabach ranges, across Huttenberg and Lölling, and farther across Wolfsberg into the Lavant valley. The limestone in which the several beds of these series are intercalated is itself interstratified between mica schists and gneisses.

At the Erzberg, near Huttenberg, which in popular parlance is called the "main iron root" (Haupteisenwurze) of the country, as shown by a section (Fig. 38, after Seeland), the lower member of the crystalline schist series is the same gneiss that contains the well known mineral deposits of the Sualpe. Its strata dip southwest. It is followed by mica schist with ore-bearing limestone intercalations, as well as with intervening layers of tourmaline rock (probably a pegmatite rich in tourmaline), eclogite, and amphibolite. These are finally followed by phyllites.

The main limestone bed at Erzberg has a length along the strike of more than one and one-third miles (2,400 m.), and a thickness of 1,312 feet to 2,296 feet (400 to 700 m.). Lenses of gneiss and mica schist, together with small quartz streaks are intercalated in it, and it often carries muscovite, passing into calcareous-mica schists. Disseminated grains of pyrite, arsenopyrite, and rarely chrome-mica and realgar, occur here and there. Sometimes the limestone is ankeritic (that is to say, it contains much iron carbonate).

The spathic ironstones, which when undecomposed are called white ores on account of their light gray color, contain considerable manganese which, when weathering begins, shows on the surface as a violet sheen (blue ores) and eventually forms a large amount of wad and pyrolusite. These manganese minerals form a gray coating called mold (schimmel) over ore fragments. The orebodies have been largely transformed into limonite, and as this alteration is accompanied (despite the absorption of oxygen and water) by a loss of volume amounting to one-fifth of the original mass, the

[1] F. Münichsdorfer: 'Geologisches Vorkommen am Hüttenberger Erzberg.' *Jahrb.* d. k. k. geol. Reichsanst, 1856. F. Seeland: 'Der Hüttenberger Erzberg und seine nächste Umgebung.' With plates I–IV. *Jahrb.* d. k. k. geol. Reichsanst., Vol. XXVI, 1876, pp. 49-112. A. Brunlechner: 'Die Form der Eisenerzlagerstätten in Hüttenberg.' (Kärnthen.) *Zeit. f. Prak. Geol.*, 1893, pp. 301-306.

limonite has a spongy structure. Their cavities often contain hematite stalactites, and sometimes pseudomorphs of göthite after blende.

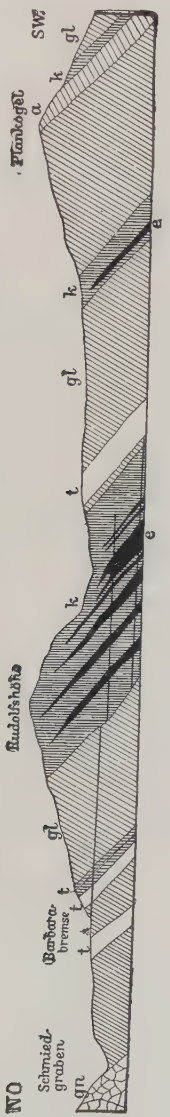

Fig. 38.—Cross-section of the Hüttenberg region. (Seeland.)
gn, gneiss; gl, mica schist; k, limestone; t, tourmaline; a, amphibolite; e, ore beds.

According to F. Seeland the spathic ironstone of Hüttenberg contains in fresher samples:

Iron	41.28 to 44.33	per cent
or Ferrous oxide	47.62 to 56.11	"
Manganese oxide	up to 5.02	"
Lime	0.79 to 1.33	"
Magnesia	3.05 to 4.35	"
Carbonic acid	32.79 to 37.70	"
Silicic acid	up to 2.47	"
Water	0.43 to 2.47	"

The different orebodies retain a partly lenticular form, but as a whole they form a rather irregular system of deposits since they overlie one another variously, both in the direction of the strike and in the direction of the thickness, or are connected by spurs. Divisions of beds recur rapidly in one and the same orebody. On a small scale, too, the outlines of the lenses next to the limestone wind about in a most irregular way, and sack-shaped spurs 6 to 10 feet long occasionally project into the underlying or

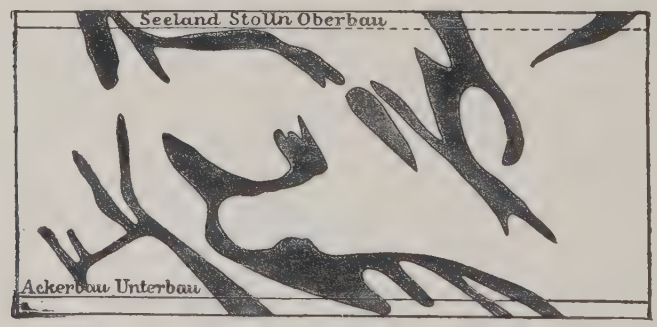

Fig. 39.—Cross-section through a part of the Hüttenberg field. (Brunlechner.) The shaded patches are ore.

overlying limestone. At the end the masses either wedge out or break up into several wedges or strings. All this is shown in the section, Figure 39. Sometimes the ore encloses also boulders of slate or limestone.

In isolated cases distinctly lode-shaped ore masses were also observed; in the Seeland shaft a schistose, well stratified limonite was traversed by a vein of younger limonite.

In the Glücklager the conditions of stratification seem to clearly indicate that the ore has been formed by a progressive replacement of the limestone. In a mass of brown ankerite [ankerite=(Ca, Fe) CO_3] obtuse-angled fragments of crystalline limestone, with an etched appearance, are found entirely isolated.

According to Brunlechner there has been a partial transposition of the ore, as follows: The surface water seeping downward absorbed the carbonic acid which had been liberated by a superficial alteration of the siderite into brown hematite. Charged with this solvent the water was now able to decompose the ironspar below the zone of oxidation. The redeposition of the ferric carbonate taken up by these waters had to occur where the water flowed away from the siderite mass and encountered $Ca\,CO_3$, that is to say, at the margins of the lenses, at the contact with the lime, through the replacement of the limestone and the exchange of the iron carbonate with the calcium carbonate. Hence it occurs that the ores of such sacklike offshoots are particularly pure. Similar replacements seem to have occurred very soon after the first layers of the limestone were deposited. However, that the iron carbonate has in the main been directly deposited as a sediment, is shown by the distinct stratification of many orebodies as well as by the manner of the connection with the series of which it forms but a member.

The Hüttenberg deposits were known to the ancient Romans. In the seventies of the last century an average of 146,000 tons of ore per year were produced, averaging 68.8%. In the nineties the annual output was, in round numbers, 100,000 tons of spathic ironstone and limonite, the output for 1898 being 7,244.1. tons of spathic ironstone, and 58,558.8 tons of limonite.

2. Gyalar in Transylvania (Hungary).

An analogous iron ore deposit exists in Transylvania, in the mountainous country south of the Maros, near Vajda-Hunyad. Crystalline limestones extend for miles through mica schist rocks and hold vast intercalations of spathic ironstone, which, however, in the levels thus far worked has in almost every case been altered into limonite. In the nineties there were produced near Vajda-Hunyad annually about 180,000 tons of brown hematite, with a content of 52 to 56% of iron.[1]

(b) Beds of Magnetite and Hematite.

1. *The Iron Ore Beds of the Archean Rocks of Sweden.*

Sweden is very rich in iron deposits, the total iron ore production of 1903 being 3,677,841 tons. There are in the main two great areas containing

[1] F. Beyschlag: 'Das Montanwesen auf der Milleniumausstellung.' *Zeit. f. Prak. Geol.*, 1896, p. 465.

these underground treasures. One lies in central Sweden on both sides of the 60th degree of latitude; it is the long famous Jernbäraland, with the well-known mines of Persberg, Taberg-Nordmark, Striberg, Grängesberg, Norberg and Dannemora. The other field lies far to the north, immediately north of the Polar Circle; it consists of the much discussed fields of Gellivara and those of Luossavaara and Kiirunavaara and Svappavare in the province of Norrbotten, described previously. With the exception of the last named, all the deposits belong to the crystalline schists whose classification must, for that reason, be briefly described in order to define the geologic position of the occurrences.

According to A. E. Törnebohm[1] the primitive rocks of Sweden are classified as follows:

Upper division..	Granites; in part also gneisses (Vermland). Phyllitic schists[2], dark hälleflintas[3] at bottom, with a diorite (Grythyttan) sheet. Porphyroid and hälleflintas. Fine-grained, scaly gneisses (the so-called granulites or eurites). Banded gneissoid granulites.[4]
Lower division..	Red and gray granites and granitic gneisses. Banded gneisses as well as cordierite gneisses (eastern Sweden) and epidote gneisses (western Sweden). Iron gneisses (with finely interspersed magnetite).

Iron ores and crystalline limestones—the two almost always found together—occur but rarely in central Sweden in the lower series of gneisses, but are very abundant in the upper, in the group composed of granulites, porphyroids and hälleflintas. Both magnetite and hematite ores occur; the former are closely associated with either limestone or with a rock consisting essentially of pyroxene and hornblende, often carrying garnet and epidote, rock called *skarn* by Swedish authors. The hematite ores, on the contrary, are usually directly interbanded with the granular gneisses.

In the description of examples from the mining fields it is advisable to begin with Norberg, because it contains a great variety of ore types crowded

[1] Törnebohm: 'Ofverblick öfver Mellesta Sveriges Urformation.' *Geol. Fören. Förh.*, Vol. VI, part 12.

[2] Phyllite is a semi-crystalline somewhat metamorphosed clay slate containing sericite, ottrelite, ilmanite and garnet.

[3] Hälleflinta, an exceedingly compact hornstone-like rock formed of microscopic particles of feldspar and quartz with scales of mica and chlorite. Porphyroid is a fibrous schistose siliceous micaceous rock with scattered porphyritic crystals of feldspar and quartz.

[4] Granulite, a schistose rock (German and English usage), with peculiar granular structure resulting from crushing and re-crystallization Not a granite as understood in French. Composed of feldspar, garnet, etc.

into a small space. Among the many others we select Persberg, Dannemora and Grängesberg.

I. Norberg.

"Norberg Bergslag," in Westmanland, contains several hundred iron mines distributed over a narrow zone 12 miles (20 k.) long and 2 miles (3 k.) wide. All these mines lie in a zone of fine-grained, scaly micaceous gneisses (granulites of Swedish authors) and of hälleflintas, bounded on both sides by granite and gneiss, and containing intercalations of mica schist as well as of crystalline limestone and dolomite. Three kinds of ore occur there: (1) Red hematite ores, consisting of crystalline hematite with numerous exceedingly thin quartzite lamellae, often crumpled and handsomely folded by rock pressure, to which is given the name dry ores, *i. e.*, needing a flux; (2) finely crystalline magnetic iron ore intermingled with a garnet-pyroxene-skarn; they need no flux and hence are called self-fluxing ores; (3) magnetic iron ores, mostly highly manganiferous (at Klackberg up to 7% of Mn_2O_3) in lenses in the midst of the dolomite and limestone, and hence highly calcareous, being called fluxing ores because as a rule they are added to others to make a smelting mixture.

The dry quartzose hematite ores which occur under precisely similar conditions at Striberg[1] in the Örebro area, and hence are called by Swedish authors "iron ores of the Striberg type," are, in the main, confined to the lower geologic horizon of the ore zone. Above them come the ores associated with pyroxene skarn, and in the uppermost horizon the calcareous fluxing ores of the dolomite intercalations predominate[2]. The iron contents of the ore vary between 43 and 60%, with a phosphorus content of only 0.004 to 0.035%. During the years 1891 to 1895 the average annual output was 172,516 tons of iron ore[3].

Sometimes the magnetic iron ores associated with limestone contain an admixture of pyrite, and hence have to be roasted before being put in the furnace, as for example at Klackgrufva. In some mines the pyrite is accompanied by such an abundance of other sulphide ores, especially galena

[1] Birger Santesson: 'Beskrifning till Karta öfver Berggrunden af Orebro Län II. De vigtigare Grufvefälten.' Stockholm, 1889.

[2] A. E. Törnebohm: 'Om lagerföljden inom Norbergs malmfällt med karta.' *Geol. Fören Förh.*, Vol. II, 1874-75, p. 329. Also see G. A. Granström: 'Nagra underrättelser om grufvorna och grufdriftn inom Norbergs berslag.' *Jern-Kontorets Annaler*, 1876, p. 1.

[3] Törnebohm: 'Geologiska Öfversiglskarta öfver Mellersta Sveriges Berslag Blad. 1 med Beskrifning,' 1880. Nordedström's 'Katalog Mellersta Sveriges Grufutställning.' Stockholm, 1897.

and chalcopyrite, as to pay for their working. (See further account under Epigenetic Ore Beds.)

II. Persberg[1].

The iron ore mines of Persberg, which according to legend were worked as early as 1390, lie in Vermland on the peninsula projecting into the Yngen Lake, in a low, hilly country. Although the production has declined, the annual average from 1891 to 1895 was 31,884 tons of ore, in which the iron content was 53 to 60% in the better ores. Magnetite (svartmalm) is the only ore produced. The best grades contain only slight admixtures of pyroxene in their fine crystalline mass. The poorer grades enclose also garnet and talc. The phosphorus content amounts on an aver-

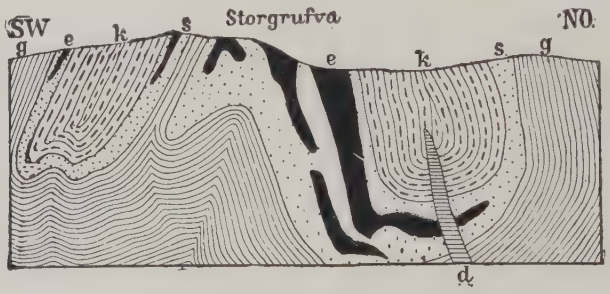

Fig. 40.—Section through the Storgrufva at Persberg.

g, Microgranular scaly biotite gneiss; k, limestone and dolomite; s, skarn; e, orebodies; d, diorite.

age only to 0.002, at most 0.013%. The manganese content varies between 0.20 to 0.35%.

The surrounding rock also consists here of a so-called granulite, an exceedingly fine-grained gneiss which in many cases passes into dense looking hälleflinta-like rocks and adjoins extensive granite areas. The orebodies form lenses or often very irregular and wholly shapeless masses, imbedded in the garnet and epidote-salite skarn. The skarn occurs either as an independent intercalation in the granulite gneiss or at the boundary of several large beds of crystalline limestone and dolomite, inserted in the granulites.

The association of these strata is apparent from the accompanying profile through the Storgrufva (Figure 40). The skarn, together with the ore beds, takes part in all the numerous foldings of the country rock. The skarn

[1] A. E. Törnebohm: 'Karta öfver Berggrunden inom Filipstads Berslag,' 1874. The same author: 'Geognostisk Beskrifning öfver Persbergets Grufvefälte,' 1875. Walfr. Petersson: 'Högbergs faltet vid Persberg,' 1897. Nordenström's 'Katalog.'

beds in the Högsberg field are especially strongly folded and crumpled. Walfr. Petersson states that he ascertained that at the flexure points of the arches, *i. e.*, anticlinal folds, the largest orebodies are to be found. A special kind of skarn, consisting mainly of talc, prevails in the area of the Alabama mine. Sometimes the skarn shows a bedlike stratification of alternating layers of garnet and pyroxene, but this is mostly confined to its barren portions. The ore beds are either sharply defined or pass gradually into the skarn by transitions containing more and more of its mineral constituents. On the other hand, pyroxene-bearing bands may at times be seen occurring in the granulite and thus effecting a transition to the skarn. In some parts of the mine magnetic iron ore is filled with stringers of calcspar.

In many places so-called *sköl*ar are seen to run through the ore beds. By a *sköl* the Swedes understand a zone of slipping or movement, mostly vertical, and generally nearly parallel to the strike, its filling consisting of crushed rock, mostly altered and either chloritic or serpentinized. They may be several meters in thickness, and in mining sometimes cause the loosening of large portions of the walls.

III. Dannemora[1].

The famous Dannemora mine lies near the railway line from Upsala to Gefle, in a low, hilly country, on the shore of the reed-bordered Grufva lake. Directly east of the mines are the furnaces of Osterby, where the choice Dannemora steel is obtained from the ore of this mining field. The mines are mentioned as early as 1481, although the real industry began only in 1532. From 1891 to 1895 the average annual output was 55,440 tons of iron ore, and 390 tons of zinc-blende.

The Dannemora ore is a very dense magnetic iron ore, with 20 to 65% of iron, averaging 50%, the percentage of iron depending upon the amount of the intermingled actinolite (a variety rich in manganese called dannemorite) as well as on the calcspar.

The geologic conditions are as follows: A broad mass of granite, the Upsala granite, partly gneissoid, occurs intruded in a very thick series of bands of hälleflinta, fine-grained gneiss (granulite, eurite of Swedish authors) and crystalline limestones, carrying considerable manganese. The hälleflinta of the Dannemora has for a long time attracted the attention of geologists. It consists of eruptive rocks, in part clearly recognizable as quartz porhpyry, in part of strongly altered porphyry tuffs, which may alternate with the limestone in layers, sometimes as thin as a sheet of paper: thus distinctly showing their sedimentary origin. The orebodies occur in

[1] A. E. Törnebohm: 'Geologisk Atlas öfver Dannemora Grufvor vid Beskrifning.' Stockholm, 1878.

three main bands, which are found intercalated in the limestone, or between it and the hälleflinta. These ore belts strike north-northeast for a distance of over a mile (2 km.) and dip northwest at 75 to 80°.

The largest of the ore lenses, situated in the middle field, has been exposed by a vast open-cut, whose almost vertical walls descend to a depth of 475 feet (145 m.). (See Fig. 41.) The present workings are all underground, below the floor of this gigantic open-cut. This orebody has a thickness of 98 feet (30 m.) and has been produced by the convergence of three closely adjoining parallel lenses.

At the boundary between the limestone and the ore masses, which are often distinctly stratified, a layer of skarn is often developed; this is an

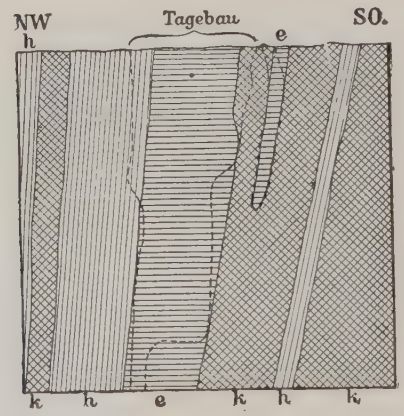

Fig. 41.—Cross-section through Storrymningen at Dannemora. h, hälleflinta; k, limestone; e, iron ore; Tagebau-open-cut.

amphibole salite rock, frequently garnetiferous, and with streaks of magnetite. At many points in the field dikes of felsite-porphyry and diorite cut across the beds.

A peculiar feature of the Dannemora field is seen in the Svafvel mine in the southern field. At this place the ore beds and accompanying rocks are obliquely traversed in strike by a broad lodelike zone of impregnation extending from the surface to a depth of about 213 feet (65 m.). This often contains good-sized masses of pyrite and zinc-blende, with accessory galena, magnetic pyrite, copper pyrite and arsenopyrite. A similar impregnation with secondary sulphide ores, but following the strike of the strata, is observed at a depth of about 754 feet (230 m.). The Dannemora south field formerly produced up to 2,000 tons of blende per year.

Finally mention may be made of the remarkable occurrence of asphalt

in small calcspar veins traversing the iron ore beds, asphalt pellets being enclosed by calcite skalenohedrons.

IV. Grängesberg[1].

Grängesberg is at present the largest iron ore district of central Sweden. The geologic mode of occurrence is as follows: The field is about 3 miles (5 km.) long and 0.6 mile (1 km.) wide, lying in the granulite zone of the primitive rocks, whose prevailing type is a fine-grained scaly biotite gneiss. The principal ore beds occur in the lower strata, in which there is intercalated at Grängesberg a vast bed of a coarse, fibrous, reddish granite gneiss. All the schists strike north-northeast and dip steeply east-southeast. The district is divided into four parts, the Lomberg field at the south, the Ormberg and Risberg field at the west, the Export field at the east and the Norra-Hammer field at the north. The first two contain a very great number of small beds of hematite carrying an admixture of magnetite and a phosphorus content of 0.02-0.8%. These ores are in part associated with the pyroxene skarn, in part intergrown with calcspar.

The conditions are totally different in the Export field. In the first place, we are here dealing with far greater deposits. They consist in the main of two great lenticular masses. In the southernmost mass the greatest thickness in the Bredsjö mine is 212 feet (65 m.), from there northward it has for a great distance a thickness of 100 to 130 feet (30 to 40 m.), until finally the lens wedges out abruptly. This, however, includes a number of intervening beds 10 to 13 feet (3 to 4 m.) thick, as well as intercalated pegmatite masses. The orebody proper consists exclusively of fine-grained crystalline magnetite, with 60 to 62% of iron and 0.7 to 1.2% phosphorus. Quartz, feldspar, fluorspar and actinolite are accessory constituents. The great northern ore lens of Sjustjernsberg, whose exposures form the Bergsbogrufva, attains a length of 1,312 feet (400 m.) along the strike, and a thickness of 295 feet (90 m.). The upper part consists of magnetite, which, however, contains so much apatite that the phosphorus content may rise to 2.8%; moreover, layers of almost pure apatite rock up to 0.06 to 0.1 feet (2 to 3 cm.) in thickness are not infrequently intercalated in the ore. The lower half of the lens, on the other hand, consists of hematite ore with 0.5 to 2% of phosphorus. At times large octahedrons of magnetite are found sparsely scattered through the fine-grained crystalline hematite. The Bergsbo lens also carries some intervening beds of granulite, which may attain a thickness of 8 meters. From their course it is seen that the entire ore mass must be regarded as a complex of several closely crowded lenses. Furthermore, the ore is frequently traversed by vast intrusive stocks

[1] N. Hedberg: 'The Grängesberg Iron Mines in 1898.' Falun, 1898.

and dikes of pegmatite. This rock, poor in mica, contains apatite, beryl, and, curiously enough, asphalt in kidney-shaped or drop-shaped pieces in the midst of druse-like portions, also as inclusions in feldspar and quartz. Where the larger pegmatite dikes traverse the hematite ore they have transformed it into magnetite, sometimes for a distance of 6.5 feet (2 m.) from the contact. It is also affirmed that the iron ores in the vicinity of the pegmatite have a higher phosphorus content, up to 2.8%.

The northernmost mining field, Norra-Hammargrufva, yields a magnetic iron ore exceedingly rich in apatite, and holding 6 to 8% of phosphorus. The immediate country rock is a hornblende gneiss with layers rich in mica. This particular occurrence at Grängesberg shows very great petrographic similarity to the Gellivare ores. The ores of Norra-Hammargrufva are characterized by pegmatitic segregations with large individuals of titanite, with hornblende and asphalt, sometimes also with scheelite and zeolitic minerals.

Nowhere in the Swedish iron ore fields are there more distinct indications of the genetic conditions of these ore masses than just here at Grängesberg. When we see how, for example, in the Mor mine an alternation of extremely thin layers of normal granulite and magnetite-bearing rock is repeated a thousand times, there can be no doubt that the magnetite and hematite were crystallized out simultaneously with the ingredients of the country rock. This is confirmed by microscopic investigation. In the rock of the Mor mine just mentioned the magnetite is clearly of the same age, and is syngenetic with the quartz, orthoclase, plagioclase and mica, of which the striped granulite of that mine is chiefly composed. It occurs partly in grains and partly in concentric layers about other minerals; also as inclusions in the midst of quartz and feldspar, while conversely it may enclose the minerals named. The same is true of the apatite-rich ores of the Bergsbö lens. Here, too, oft-repeated alternations of ore and rock and the microscopic conditions of mutual intergrowth show a simultaneous crystallization of ore- and rock-forming minerals. In the apatite-rich ores of Norra-Hammargrufva the microscopic sections suggest, it is true, a certain succession in the segregation of the several ingredients, which is absent in the examples above mentioned. The apatite of the latter mine is always free from inclusions, and this, together with the abundant brown titanite, seems in each case to have been the earliest formed mineral in the various layers of ore. Next in age follows the hornblende, then the infrequent quartz and finally the fluorspar. The magnetite existed before the hornblende only in small individuals, for only in this form is it found enclosed in the hornblende. Subsequently it filled the gaps between the hornblendes in the form of larger grains and aggregates.

The question as to the form in which the iron compounds were present in the rock before they were altered by regional metamorphism cannot be definitely answered. Their present mineralogic nature, however, was certainly imparted to them simultaneously with the general alteration of the rock. The mineral wealth of Grängesberg seems destined to last for many years. Inasmuch as on Vestra Ormberg an orebody has been followed to a depth of 984 feet, it is fair to assume that the others also extend far down.

The total production from Grängesberg (629,802 tons) in 1897 exceeded that of Norberg, and by a small amount that of the Gellivare field of northern Sweden, which in 1897 produced only 623,110 tons. This great development has, however, taken place only in recent time; though the ore beds of Grängesberg have been known since the beginning of the 17th century, they have been worked but little. The very largest deposits were practically untouched because the high phosphorus content of the ores rendered them unsuitable for furnace treatment. It is only since the invention of the Thomas basic Bessemer process that the revolution took place here, and all at once production increased tremendously. The many companies which formerly operated small mines are now consolidated into four large companies. By far the larger part of the phosphoric ores is at present shipped from the port of Oxelosund, in eastern Sweden. The bulk of it goes via Stettin and Rotterdam to upper Silesia and Westphalia.

In the following table we give some typical analyses of different varieties of iron ores from central Sweden taken from four localities:

I. Pyroxene-bearing magnetic iron ore of the Storgrufva at Persberg. (Average sample taken by W. Petersson.)

II. Quartzose hematite ore from Striberg (Kärrgrufva). (C. J. Särnström, analyst.)

III. Apatite-bearing hematite ore. . . . . } From Grängesberg, Bergsbö mine,

IV. Apatite-bearing magnetic iron ore. . . . } after N. Hedberg.

	I.	II.	III.	IV.
Magnetic oxide		26.78	14.81	79.04
Ferric oxide	55.24	47.32	73.50	9.13
Ferrous oxide	23.80	.....	.....	.....
Iron	57.18	52 52	62.18	63.63
Manganese oxide	0.21	0.19	0.04	0.10
Lime	5.17	0.95	5.09	3.61
Magnesia	1.85	0.40	0.82	2.72
Alumina	2.38	0.35	0.63	1.78
Silica	10.45	23.80	1.62	2.00
Phosphoric acid	0.007	0.034	3.53	2.42
Phosphorus	0.0033	0.015	1.54	1.06
Carbon dioxide	0.51	.....	.....	.....
Sulphur	0.02	0.020	Trace.	0.013
Copper	Trace.	.....	.....	.....
	99.637	99.844	100.04	100.813

V. The Iron Ore Deposits in the Province of Norrbotten, Gellivare and Svappavara.

The famous ore mountain of Gellivare,[1] 80 kilometers north of the Polar Circle, in Swedish Lapland, province of Norrbotten, which is now connected by a railway line of 132 miles (220 k.) with the port of Luleå, and is to be connected in the near future by the Ofoten railway with the Norwegian coast, is the largest iron ore deposit of Scandinavia. About one-twentieth of the slopes of the mountain, in all about 65 hectares, are occupied by the outcrops of the iron orebodies, arranged in two series. The prevailing country rock, in which the beds are intercalated, is a coarse-grained, reddish gneiss, which is seen outcropping especially on the slope of the 'Välkomann' peak. Farther south it becomes more fine-grained, and contains a good deal of hornblende. It is always garnetiferous. Toward the west it passes over into hälleflinta[2]. At the Capitan and Frederika grants, and thence to the Tingfall peak, it is banded, owing to the development of layers especially rich in hornblende, and in such case shows intense folding. The gneisses and ore are often broken through by granite, as at Välkomman and Kungsryggen.

The series of ore lenses take part in all the changes of strike of the granite, even the finer plications.

The ore consists of magnetite and hematite, and is usually rich in apatite, sometimes even passing over into apatite rock proper. Out of 41 samples 26 showed an iron content of 70 to 74.3% ; 13 a content of 60 to 70% ; 2 a content of 50 to 60%. The phosphorus content varies from 0.05 to 1.5%. The sulphur content is quite insignificant. The manganese content is only about 0.15%, and titanic acid 0.45 to 1.9%.

The outcrop of the orebodies is in part concealed by glacial drift.

Gellivare has been officially known as a mineral deposit since 1704. It was only in 1797 that Hermelein, to whom the development of Lapland is so largely due, established an industry of note in this locality. Transportation was effected solely in winter by means of reindeer. The Koskull and Capitan mines were then the largest. In 1837 that first mining period attained its greatest annual production, with 540 tons. After 1870 the work was almost entirely abandoned, but of late years there has been a remarkable development, as noted previously.

[1] 'Berättelse om Malmfyndigheter inom Gellivare och Jukkasjärvi Socknar,' etc. afgiven af Chefen för Sveriges Geol. Undersökning, 1877. Contains the work of D. Hummel, O. Gumaelius, O. Trysén and C. A. Dellwik. Wedding: 'Die Eisenerzvorkommen bei Gellivara,' etc. *Preuss. Z. f. B., H. u. S. Wesen*, Vol. XLVI, 1898, pp. 69-78. For further literature consult *Förh. Geol. Fören.*, Stockholm.

[2] The Norwegian hälleflintas are exceedingly compact hornstone-like rocks produced by metamorphism from fine sediment. (Geikie.)

Svappavara lies between the rivers Tornio and Kalis, 43 kilometers southeast of Luossavaara, already described. The deposits are intercalated between mica schists and fine-grained quartzites. They were discovered as early as 1654 and were worked at that early date, but became important only in recent time. The ore resembles that of Gellivare—but that it has a higher sulphur content, which is a disadvantage. Copper ore deposits are also known in the same locality.

2. *The Iron Ore Deposits of the Arendal Region in Norway.*

In southern Norway there are iron ore deposits, formerly extensively worked, which appear to be related to those of Persberg, although Th. Kjerulf and Telleff Dahl,[1] in accordance with the state of knowledge at that time, were inclined to regard them as lode-like occurrences. The deposits are near the coast and form an ore zone about 15 miles (25 km.) long. The most important mines lay along the Langsev Vand (Langsev and Vas mines) at Näskillen and on the Hellesund on Langö and Gamö. The country rock is biotite gneiss with intercalations of mica schist, quartzite, hornblende schist and crystalline limestone. The ore consists of magnetite, with some intermingled garnet and augite, the deposits being enveloped in a mantle of skarn composed of garnet, light green augite, together with some epidote and calcite. The various ore masses are irregularly lenticular in shape, and attain a thickness of 6.5 to 65 ft. (2 to 20 m.), with a length along the strike of 300 to 650 feet (90 to 200 m.). While the boundary between garnet skarn and country rock is very sharply defined, stringers of ore frequently penetrate the skarn, the ore occurring also in smaller lenses by itself in the surrounding gneiss. The fragments of the country rock described by Kjerulf and Dahl in these deposits may indicate local disturbances. The ore beds themselves and the pegmatite veins by which they are traversed are rich in various minerals, including some rare species.

3. *The Iron Ore Deposits of Krivoi-Rog, in Southern Russia.*

These ore deposits[2], ordinarily grouped as those of the Saxagan basin, lie on the Inguletz, a western tributary with north-south course entering into the Dnieper river above Cherson. They are of exceedingly great importance to Russia, because they lie close to the Donetz coal basin extending east of

[1] Th. Kjerulf and Tellef Dahl. 'Ueber das Vorkommen der Eisenerze bei Arendal,' *Neues Jahrb. f. Min.*, 1862, p. 557.

[2] See reviews of the works of Kontkiewitsch, Piatnitzky, Domherr, Monkowsky, Karpinsky, and others: *Zeit. f. Prak. Geol.*, 1896, p. 271; 1897, pp. 182, 186, 278, 374; 1898, p. 139 (Macco). See also, L. Strippelmann: 'Süd-Russlands Magneteisenstein u. Eisenglanzlagerstätten in den Gouvernements Jekaterinoslaw u. Cherson,' 1873. J. Cordeweener: 'Geologie de Krivoï-Rog et de Kertsch.' Paris, 1902.

the Dnieper. The ores occur in a strongly folded crystalline schist striking north-south, whose geologic age is as yet uncertain. In its upper part this rock consists of carbonaceous slate with but few layers of ore; next below come the ore-bearing quartzite schists, underlaid by clay slate, actinolite schist, quartz chlorite schist, talc schists, arkose and itacolumite-like mica schists, and finally by gneiss (probably dynamo-metamorphic granites) and true granites. The ore-bearing strata form a long-extended fold, and show a close minor plication by which quartzite beds have, according to Macco, changed into a succession of quartzite nodules, like conglomerate cobbles in a clay slate. In the double row of deposits extending parallel to the Saxagan river the two most important orebodies are those near Krivoï-Rog; the lower one about 98 feet (30 m.) and the uppermost about 262 feet (80 m.) thick. The ores consist of magnetite, for the most part altered to red hematite, with 45 to 70% of iron and 0.01 to 0.02% P_2O_5. The very irregular ore masses lie in a finely banded yellowish white, red or brown ferruginous quartz schist whose crystalline quartz grains enclose numerous magnetite particles. In 1894 the production of Krivoï-Rog had already risen to 880,000 tons, and by 1900 to about 2,700,000 tons. According to J. Cordeweneer there are about 73,000,000 tons of ore yet available.

4. *Iron Deposits of Spain (El Pedroso) and the Bukowina.*

Spain, also, possesses important iron ore deposits in crystalline schists, which recently have been worked on a large scale. At El Pedroso,[1] on the south slope of the Sierra Morena, famous for its mines, there is in the mining field of Juanteniente, northeast of Seville, a hematite deposit 4 to 5 meters thick, interbedded with upturned mica schist; it has been followed over 600 meters. Near Navalazaro another magnetite deposit 19 to 26 ft. (6 to 8 meters) thick, containing some granite and pistazite, has been disclosed in the midst of the gneiss. Further discoveries have been made lately in this region by means of magnetic prospecting.

A brief mention should be made of the magnetic iron ore deposits in the mica schist area of southern Bukowina (Rusaja mine and others)[2].

5. *Archean (Laurentian) Magnetic Iron Deposits of North America.*

Deposits of magnetic iron are found in various places in North America in Archean gneisses and crystalline limestones. The most important are

[1] F. Römer: 'Ueber die Eisenerzlagerstätten von El Pedroso in der Provinz Sevilla.' *Z. d. D. G. G.*, 1875, pp. 63-69.

[2] B. v. Cotta: 'Lehre vom den Lagerstätten der Erze,' II, p. 260. B. Walther: *Jahrb.* d. k. k. geol. Reichsanst., 1876, pp. 391, 415.

found in the hills of southeastern New York and northern New Jersey (Tilly Foster mines, Forest of Dean mine), and in western North Carolina (Cranberry).[1]

6. *Pre-Cambrian (Algonkian) Iron Ore Deposits of North America.*

Marquette Iron Ore District in the State of Michigan.

Deposits belonging only in part to the class of syngenetic stratified deposits, probably more properly to the metasomatic formations, are those of the Marquette district, in the State of Michigan, which have recently been the subject of painstaking study. According to Van Hise and Bayley[2] the geologic conditions there are as follows:

This district is about 29 miles (65 km.) long and 1.2 to 3 miles (2 to 5 km.) wide, extending along the south shore of Lake Superior between Mar-

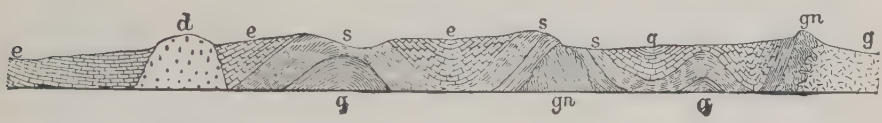

Fig. 42.—Profile through the area south of Negaunee. (Van Hise.)
gn, gneiss; g, granite; q, quartzite; s, clay slate; e, iron-bearing Negaunee strata; d, diorite and diabase.

quette and Michigamme. The oldest bedrock consists of Archean mica schists, hornblende schists, gneisses, granite gneisses and intrusive granite masses. Above these, as shown in profile (Fig. 42) come the unconformable Algonkian (Huronian) formations, the lower and the upper Marquette. The first consists of quartzites, dolomites, schists and the iron-ore-bearing Negaunee strata; the latter of quartzites, schists, graywackes and conglomerates, in part marked by strong regional metamorphism as well as basic eruptive sheets

The iron-bearing Negaunee formation, 984 to 1,476 feet (300 to 450 m.) thick, is in its lower level, where it is found unchanged, mainly formed of finely banded sideritic slate, consisting of alternating lamellae of spathic iron ore and quartz, and containing about 30 to 40% of ferrous oxide. These slates, however, are very commonly altered in the lower levels by metasomatic processes into grunerite-magnetite slate. These are composed

[1] J. Kemp: 'Ore Deposits of the United States,' 1900, p. 166. H. B. Nitze: 'Iron Ores of North Carolina,' N. Car. Geol. Surv., *Bull.* 1, 1893. Arthur Keith: Cranberry folio, Geologic Atlas of the U. S., folio No. 59. Washington, 1903.

[2] Van Hise and Bayley: 'The Marquette Iron-Bearing District of Michigan.' With Atlas. Washington, 1897, U. S. Geol. Survey, *Monograph* XXVIII. J. E. Jopling: 'The Marquette Range, its discovery, development and resources.' *Trans.* Amer. Inst. Min. Eng., Vol. XXVII, 1898, pp. 541–555.

of thin layers of quartz, magnetite and grunerite, the almost pure ferric silicate in the form of hornblende. In many cases they also carry a garnet of secondary origin. These metasomatic processes are supposed, by the above-named authors, to be connected with the intrusion of the diabase characteristic of the entire Negaunee group. These diabases have been intruded in vast stocks and penetrate through the ore-bearing strata in numerous dikes.

Subsequent alkaline solutions are supposed to have passed through the sideritic slates and occasioned the exchange of the iron carbonate with alkaline silicates. At the higher levels, on the contrary, the sideritic slates by recrystallization under the influence of atmospheric seepage water, entering the deeper strata with its charge of oxygen, have been formed into hand-

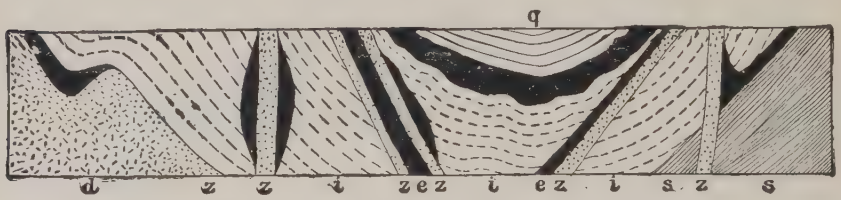

Fig. 43.—Diagram showing the occurrence of the iron ores of the Marquette district. (Van Hise.)

s, schist; i, Jasper schist; q, quartzite; d, diabase and diorite; z, decomposed diabase and diorite; e, orebodies.

somely banded hematite-limonite-quartzites. In these, strata of specular ore and hematite are seen to alternate with bands of ferruginous quartz or jasper, which in many areas have been subjected to great pressure and curiously folded or often comminuted into a breccia. Crystalline hematite has at the same time penetrated into the cracks between the individual jasper fragments. From the chemical mobility of the iron compounds of the Negaunee strata the authors infer the origin of the orebodies forming the actual object of the mining industry. These orebodies consist partly of distinctly granular-crystalline to dense hematite mixed with magnetite (hard ores) partly of red hematite, with transitions into brown hematite (soft ores).

Though the orebodies in general are associated with a definite stratigraphic horizon, yet their position in detail, as appears by investigation, is dependent on structural conditions. The ore masses are always found in synclines of folded, impermeable rocks, or in troughs formed of such strata, or in basins formed by impermeable chloritic and talcose eruptive rocks, as shown in the accompanying section (Fig. 43). These solid ore masses, therefore, cannot have been formed by direct sedimentation, al-

though they may have originated genetically from the undoubtedly sedimentary sideritic slates. Accordingly they are supposed to be rather enrichment formations deposited by iron-bearing water penetrating downward, which received their charge from the upper strata greatly disintegrated by the folding process.

They would thus constitute an excellent example of ore deposits which have to be explained by the aid of the descension theory (see later). The greatest objection to this theory is its failure to show how the silicic acid was removed from the quartzose rock masses in order to leave the spaces free for the invading iron ore, thus finally forming compact orebodies. The authors of the monograph ascribe this action to alkaline compounds derived from the diabasic rocks.

Other deposits similar in character and genesis occur in the Menominee district, on the boundary between Michigan and Wisconsin, as well as of Penokee-Gogebic district in the latter State, and the Vermilion and Mesabi districts north of Lake Superior in Minnesota[1].

In 1903 the annual production of all the iron ore fields in the vicinity of Lake Superior was 26,573,271 long tons. The composition of the ores is shown by the following analyses, the material being dried at 100° C.:

	Marquette Range. (Barnum)	Menominee. (Appleton)	Gogebic. (Anvil)	Vermilion. (Chandler)	Mesabi Range. (Adams)
Iron	65.30	63.30	62.74	64.70	64.18
Silicic acid	3.49	4.61	4.09	4.26	2.80
Phosphorus	0.075	0.018	0.055	0.036	0.035
Manganese	0.36	0.27	0.82	0.13	0.40
Alumina	1.79	1.30	1.10	1.37	0.80
Lime	0.33	0.52	0.47	0.33	0.21
Magnesia	0.26	0.47	0.11	0.10	0.10
Sulphur	0.026	0.019	0.018	Trace.	0.007

The subject of the origin of the Lake Superior iron ores has been investigated by a number of geologists during a long term of years. Prof. R. D. Irving at first adopted the theory that the ores were due to the replacement of the limestone, but he afterwards abandoned it, considering that the original rock must have been an iron carbonate and not a carbonate of lime. For the ores of the Vermilion Range of Minnesota, N. H. and H. V. Winchell propounded the explanation that they were due to direct precipitation from the waters of a hot primordial ocean. Alternating conditions produced from these waters alternating precipitations of iron and silica, forming the characteristic banded ores.

[1] H. V. Winchell: 'The Lake Superior Iron Ore Region,' *Inst.* of Mining Engineers (Eng.), 1897. Irving and Van Hise: *Monograph* XIX, U. S. Geol. Survey, 1892.

It was held by J. D. Whitney as early as 1854 that the iron-bearing rocks of the Lake Superior region were volcanic rocks, erupted in practically their present condition, and this view was held by subsequent geologists. To this supposed volcanic rock the name jaspillite was given. In their monograph on the Penokee-Gogebic iron range, Irving and Van Hise came to the conclusion that the iron was originally precipitated as carbonate or oxide, and that the accompanying chert was simultaneously precipitated. It is supposed that the atmosphere was more highly charged with carbonic oxide than at present, and that the general temperature of the earth's crust was somewhat higher. J. E. Spurr[1] studied in 1893 the iron ores of the Mesabi Range in Minnesota and found the rocks substantially like those of the Penokee-Gogebic Range. However, the iron carbonate, which, according to the researches of Irving and Van Hise was the oldest type that could be found, and was therefore held to represent nearly the condition of the original rock, was found on the Mesabi to be in nearly all cases of undoubtedly secondary origin and to have been formed by the carbonization of iron oxides. It was found, moreover, that all of the constituents of the rocks, including the iron carbonate and oxides and the silica, could be shown to have been derived from an original green ferrous silicate which Spurr classed as glauconite, although the analysis showed very little potash. This explanation of the origin of the Mesabi ores has been accepted generally. Recently the work of Leith on the Mesabi Range[2] confirms Spurr's observations concerning the nature of the original mineral, its manner of formation and the manner in which iron carbonates and oxides are derived from it. On account of the scarcity or lack of potash, the writer objects to the name glauconite for the original ferrous silicate and coins a new name, greenalite. Spurr[3], however, after a review of the evidence, is still in favor of retaining the name glauconite for the Mesabi mineral, although acknowledging, as before, that it constitutes a somewhat unusual variety.

7. *African Iron Ore Deposits in Crystalline Schists.*

Among these the best known are the numerous iron ore deposits which France possesses in Algiers. The most important of them have hitherto been those of Mokta-El-Hadid (or Ain Mokra) in the Department of Constantine, at the foot of the south slope of the Coast Range, between Cape de Fer and Bône, near Lake Fezzara.

The ores consist of magnetite and red iron ore, and occur interbedded with limestones, forming part of a series of garnetiferous-mica schists, in-

[1] *Bull.* Minn. Geol. Surv., No. 10, 'The Mesabi Iron-Bearing Rocks.'
[2] *Monograph* XLIII, U. S. Geol. Surv.
[3] *Amer. Geologist*, June, 1902.

tercalated in crystalline gneisses. The main ore deposit has a thickness of 40 meters (131 ft.). The production in some years rose to 430,000 tons[1] (1874). Other important occurrences have recently been exploited.

Mention may also be made of the red hematite intercalated in the quartzite of the crystalline schists in the German possession of Togo at Banyeri, Kabu and Basari.[2]

(c) Origin of the Iron Ore Deposits of Crystalline Schists.

To the remarkable works of Hj. Sjögren and J. H. L. Vogt[3], on which the following remarks are in the main based, we owe some deeper insight into the genesis of the iron ores of the crystalline schists. It cannot be said, however, that the question of their genesis has as yet been conclusively answered.

The theory of a direct sedimentary origin of the magnetite and hematite ore deposits is sustained, according to Vogt, by the following facts:

1. Their complete conformity with the country rock.
2. Their very pronounced stratification.
3. Their association with definite stratigraphic horizons.
4. Their frequent association with limestone.
5. The occurrence of chemically similar formations in younger non-metamorphic formations.

Sjögren is inclined to regard the older Swedish iron ore deposits as lacustrine or terrestrial, at most as littoral, which he supposes to have been segregated from very dilute iron solutions in the manner of bog ores and lake ores (see p. 101), that is, with the aid of vegetable material. In point of fact this hypothesis is supported by the occurrence in many deposits of substances probably of vegetable origin, such as petroleum, asphalt, bitumen and anthracite. The stock-like or lenticular form of many old iron ore deposits is also readily explained if we imagine that they were deposited on a somewhat uneven surface under lacustrine conditions. On the other hand, it must be remarked that we know also of younger genuine marine iron ore deposits even containing mineralized ammonites and sea urchins, such as those of the Brown Jura and the Eocene. While this is true in the individual cases, it must be assumed that the iron ores were primarily deposited at the bottom of some body of water from highly dilute solutions. The formation of such solutions is to be explained by the decomposition of the finely interspersed iron ores and ferrous silicates contained in so many

[1] E. Fuchs and L. de Launay: 'Traité des Gites Minéraux,' 1893, I, p. 721.

[2] Fr. Hupfeld: 'Die Eisenindustrie in Togo.' *Mitth.* a. d. deutschen Schutzgebieten, Vol. XII, 1899, part 4, pp. 175-193.

[3] Hj. Sjögren: 'Om de svenska jernmalmlagrens genesis,' *Geol.* Fören i. Stockholm, Förh. 13, 1891, p. 373. J. H. L. Vogt: 'Salten och Ranen,' Christiania, 1891.

older rocks, through the agency of terrestrial water charged with carbonic acid, sulphuric acid or organic acids. (On this mode of precipitation of iron, see p. 102). The decomposition undoubtedly must have originally taken place in many cases in the form of iron carbonate. This was in most cases at once further oxidized into ferric hydrate. Only with an abundance of reducing organic substances could the carbonate remain as such; in most cases ferric hydrate was at once formed. The silicic acid in the quartzose iron ores may in part be derived from alkaline iron solutions. From such a solution the silicic acid is precipitated simultaneously with the segregation of ferric hydrate. The hematite ores are in general rich in silicic acid, while the magnetic iron ores are poor in that respect. The latter often carry sprinklings of sulphur ores. These facts point to reducing processes in the formation of magnetic iron ores, by which the iron was probably precipitated from carbonate solutions as carbonate, or from humic acid solutions at first as iron crenate, while during the formation of the hematite ores rich in silicic acid these reductions did not take place.

The phosphoric acid content is derived originally from the apatite of the rocks. Phosphoric acid is accumulated by plants; when they decay it passes into solution as ammonium phosphate. During the sedimentation of the iron ores the phosphoric acid was also precipitated as iron or lime phosphate.

Manganese is precipitated from solutions in the same way as iron, but since the iron is more rapidly oxidized, the manganese is precipitated later when the solution contains less carbonic acid. In this way we may explain the fact that manganese ores are ordinarily found above the iron ores and associated with limy ores, often connected with limestone and dolomite.

It was only by means of regional metamorphism, more particularly the factors which are probably most active in that process, pressure, moisture and heat, that the final alteration of the iron carbonate and ferric hydrate into magnetite and hematite was effected. Not only the ore beds, but also the country rock, undergo a complete recrystallization in this process (see remarks on p. 71 on Grängesberg).

(B) Iron Ores as Original Intercalations in Normal Sediments.

(a) Silurian Iron Ores.

1. *The Iron Ore Deposits in the Lower Silurian of Central Bohemia.*[1]

The Bohemian iron ores are intercalated in Lower Silurian strata (Bar-

[1] M. V. Lipold: 'Die Eisensteinlager der silurischen Grauwackenformation in Böhmen.' *Jahrb.* d. k. k. geol. Reichsanst., Vol. XIII, 1863, pp. 339-448. With 40 Fig. Jos. Vala and R. Helmhacker: 'Das Eisensteinvorkommen in der Gegend von Prag und Beraun.' Prage, 1873. C. Feistmantel: 'Die Eisensteine in der

rande's stage D) made up in the main of quartzites, associated with slates, graywackes, conglomerates, diabases, amygdaloids and diabase tuffs.

The ores occur within these stages at different horizons:

The lowest horizon, D_1, consisting of conglomerates, graywackes, graywacke slates, diabase tuffs and tuff slates, contains the iron ore deposits of the Sárka, Svárov, Libecov and Chynava. Two vast beds of diabase tuffs and tuffaceous slate, separated and overlain by gritty slate, are here the ore-bearing rock proper. This bed here consists of oolitic red hematite up to 5 meters in thickness, but is elsewhere a poor blackish gray oolitic chamosite (a water-bearing aluminous iron silicate with slight magnesia content). These chamosite beds attain a thickness of up to 20 meters. The several ore beds in the tuff slates form extended lenses or short beds which either wedge out or pass along the strike into tuff slate poor in iron.

An overlying horizon, D_4, consisting essentially of an alternation of graywacke slates and quartzites, encloses the ores of Jinocan, Nucic, Chrustenic and Vraz.

The most important is the ore bed of Nucic west of Prague.

The Nucic ore possesses a pronounced oolitic structure. It consists of a groundmass of light brownish gray spathic iron ore, or more frequently of dark gray chamosite, in which the ooliths are interspersed as concentric-shelled ellipsoids of chamosite. The size of these small concretions ordinarily varies between 1 and 2 millimeters in diameter. A very firm and brittle ore called sklenenka (glass ore) also occurring there is especially rich in ironspar and calcspar, which completely impregnate the groundmass of chamosite.

Owing to the high percentage of phosphorus, most of the ores are treated by the Thomas process.

The bed attains its greatest thickness of 16 in. at Nucic itself; the length in the strike has been ascertained to be 15 kilometers. It shows distinct stratification. Overlying and underlying it are graywacke slates, farther on also is quartzite with lower Silurian fossils. The ore bed itself has furnished some fossils, among them *Trinucleus Ornatus* Barr., *Asaphus Nobilis* Barr., *Orthis Macrostoma* Barr. At times the bed has been influenced and bleached by decomposing solutions. In the outcrop to a depth of 6 to 12 m. (19 to 38 ft.) the ore has been transformed into brown hematite.

The Nucic beds especially, which are either flat or but gently inclined, are cut obliquely by numerous faults. At the present time the greatest output is from the open cuts and underground workings of the two companies

Etage D des böhmischen Silurgebirges.' *Abh.* d. k. Böhm. Ges. d. Wiss. VI, Vol. VIII, 1875 and 1876. Also, 'Ueber die Lagerungsverhältnisse der Eisensteine,' etc. *Sitzungsber.* d. k. Bohm. Ges. d. Wiss., 1878, pp. 120-132.

operating the Nucic mines. The Zdic mines are the only others of importance. In 1898 Bohemia produced a total of 632,183.7 tons of iron ore. In 1899 the Prager Eisenindustrie at Nucic produced 296,734 tons; the Montangesellschaft 344,718 tons of ore, with an average iron content of 37.25%.

2. *The Lower Silurian Iron Ores of the Thüringerwald and Vicinity.*

Oolitic iron ores similar to those of Bohemia[1] occur in the lowest horizon of the lower Silurian in the Thüringerwald and the Frankenwald, as well as in the Vogtland. In recent years the deposit at Schmiedefeld (Sachsen-Meiningen) near Gräfenthal in Thüringia has become especially important.

The petrographic character of the Schmiedefeld iron ore has been studied by H. Loretz. According to this author it consists of thuringite and chamosite. The thuringite is a compact olive-green mineral with a finely foliated

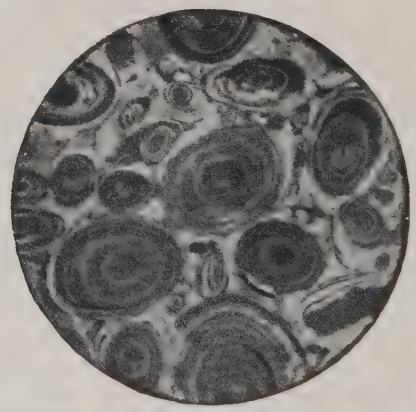

Fig. 44.—Thin section through a chamosite oolite from Schmiedefeld. (Enlarged fifty times.)

crystalline texture, which on weathering often becomes oolitic. Its average chemical composition as given by Loretz is as follows:

SiO_2	22.61	per cent.
Al_2O_3	16.80	"
Fe_2O_3	15.43	"
FeO	33.10	"
MgO	1.20	"
H_2O	10.60	"
Total	99.74	"

[1] C. W. von Gümbel: 'Fichtelgebirge,' 1879, pp. 235, 236, 420-428. Th. Liebe: 'Uebersicht über den Schichtenbau Ostthüringens,' *Abh.* z. geol. Spezialk. v. Preussen. Vol. V, part 4, 1884. H. Loretz: 'Zur Kenntniss der untersilurischen Eisensteine im Thüringer Walde,' *Jahrb.* d. k. preuss. Landesanst, 1884, pp. 120-147.

The thuringite often forms small thin layers or oolitic granules in an ordinary soft clay slate, in which case it is called thuringite slate. The chamosite, which is far more abundant than the thuringite, consists of a dark gray compact aggregate of small concentric pellets, of about the size of millet, lying close together and cemented by siderite.

We give the figure of a thin section through a typical chamosite oolite of Schmiedefeld. (Figure 44.)

The chemical composition of typical chamosite ore from Schmiedefeld (W. Böttcher) is given under (a), while column (b) shows the calculated theoretical composition of true chamosite, as calculated by H. Loretz:

(a)		(b)	
SiO_2	18.63%	SiO_2	29%
Al_2O_3	8.48	Al_2O_3	13
Fe_2O_3	3.73	Fe_2O_3	6
FeO	45.13	FeO	42
MgO	1.68	H_2O	10
CaO	0.84		
P_2O_5	0.44	Total	100
CO_2	13.00		
TiO_2	1.63		
H_2O	6.44		
Total	100.00		

The structural conditions as outlined by Loretz are as follows: The Cambrian rocks, near Schmiedefeld, are overlaid by quartzite similar to

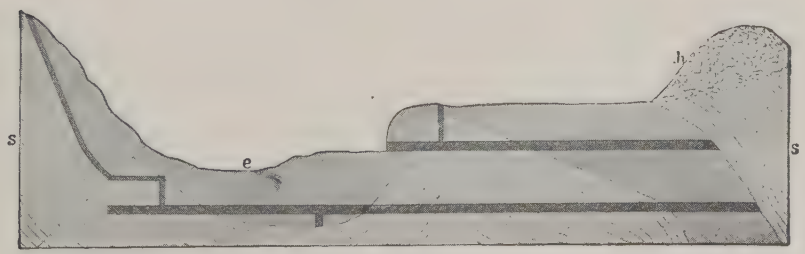

Fig. 45.—Cross-section through the main bed at Schmiedefeld.
s, clay slate; e, iron ore; h, dump.

the phycod slates and by Griffel slates, these beds forming transition strata between Cambrian and lower Silurian beds. These are overlaid by ironstone beds, followed by typical lower Silurian slates. The main iron ore bed is sometimes as much as 18 meters (59 ft.) thick and is now worked in the Maxhütte at Unterwellenborn. Its position is shown in the cross-section (Fig. 45) kindly furnished by the mine manager.

The production at Schmiedefeld for 1899 was 140,000 tons of iron ore.

A similar deposit of chamosite ore and thuringite slate occurs northwest of Hof in the valley of the Saale, and in inverted beds in the Steinach Valley of the Franconian forest. The thuringite rocks of Leuchtholz, near Hirchberg, contain numerous casts of *orthis*. (Gümbel.)

The following examples are, because of their structure, classed in the same category as the lower Silurian iron ores of central Europe.

3. *The Clinton Hematite Ores.*

The Clinton[1] iron ore received its name from the town of Clinton, near Utica, New York, where it was extensively mined. The ore is an almost constant accompaniment of the Clinton series of the Upper Silurian throughout its exposure in New York, Pennsylvania, Wisconsin, Virginia, Kentucky, Tennessee and Alabama. The ore forms one or more beds, interbedded with clay slates, sandstones and impure limestones, which are overlain by the Niagara slate and underlain by the Medina sandstone. The ore beds vary greatly in thickness and position. At Clinton three beds are known, the uppermost, 4 to 6 ft. thick, not being workable. The middle bed, 2 ft. thick, is the only one now worked. At Birmingham, Alabama, the ore is rich in fossil remains and occurs in several beds which may reach a total thickness of 9 meters (29.5 ft.).

The Clinton ore is often oolitic, and in that case is then called flaxseed ore. In this ore, from which the calcareous cement has often been leached out, the grains consist of concentric shells of iron oxide and some amorphous silica, about a nucleal grain of quartz.

Some of the deposits often consist of an aggregate of countless fragments of various calcareous marine organisms, such as bryozoa, corals, crinoids, brachiopods, etc. (fossil ore) all more or less replaced by iron oxide, and cemented by carbonate of lime. The soft ores are mostly red in color, of earthy appearance and loose texture. The hard ore is a highly ferruginous limestone. The hard ore has been found to average between 35 and 40% of iron with 0.5% to 1% of phosphorus, and is seldom a bessemer ore[2]. According to C. H. Smyth and others, these hematite beds are original deposits in an inland sea that received the drainage of an extensive area of crystalline rocks. The ferruginous and somewhat siliceous waters of this shallow body of water deposited the iron about nucleal grains of sand and replaced the calcium carbonate of the fossil fragments before the sediment forming the overlying strata was deposited. The alternative explanation of these red hematite beds by a subsequent replacement of beds of

[1] C. H. Smyth, Jr: 'On the Clinton Iron Ore.' *Am. Jour. Sci.*, June, 1892, p. 487. *Zeit. f. Prak. Geol.*, 1894, p. 304.

[2] W. B. Phillips: 'Iron Making in Alabama,' 1898, Alabama Geol. Survey.

limestone by iron-bearing seepage waters seems to us to have been completely disproved by Smyth.

The oolitic hematites of Belle Island, near Newfoundland, seem to belong to the Clinton group. They form two beds intercalated in slates and sandstones, one 3 m. (9.8 ft.) and the other 1.8 m. (5.9 ft.) thick, the ore fracturing in remarkably regular parallelopipeds.

The precipitation of amorphous silica and the formation of iron oolite is a very common phenomenon, as has been proved by Ch. Bleicher's[1] investigations upon samples of the most diverse origin.

(b) Ironstone Deposits of the Carboniferous Rocks.

Wherever the carboniferous rocks contain coal seams, there are almost always beds of iron ore of more or less economic importance. One of the most carefully investigated European examples is the following:

1. *The Iron Ores of the Ruhr Coal Basin.*

The iron ores of the Ruhr coal basin[2] are associated with the lowest and leanest coal measure of that locality. Baumler distinguishes the following occurrence:

I. A Spathic Iron Ore Measure.

This bed, which is 0.24 m. (0.7 ft.) to 0.48 m. (1.5 ft.), more rarely 1.4 m. (4.6 ft.) thick, has been traced for a distance of several miles, and has here and there been worked. It is not, however, a single bed throughout, but consists of thin lenticular beds as much as 1 km. (0.6 mile) in extent, with intervening barren layers. This ore is a yellowish gray granular crystalline spathic ironstone ore without lamination or cleavage structure and carrying 45.66% of iron (65.3% when roasted) with some carbonaceous material. Underlying the iron ore measures there is usually a layer of coal (Kohlenpacken) varying up to 30 cm. (1 ft.) thick, while a foot above the barren overlying rock often contains a layer of spherosiderite concretions. The spathic iron ore horizon lies 80 to 100 m. (260 to 328 ft.) below the Mausegatt, the leading bed of the lean measures. Of course the ore bed

[1] Ch. Bleicher: 'Sur la structure mikroscopique du mineral de fer de Lorraine.' *Compte Rendu*, 114, p. 590.

[2] R. Peters: 'Der Spatheisenstein der westfälischen Steinkohlenformation.' *Z.* d. V. Deutsch. Ing. I. 1857, p. 155. Baumler: 'Ueber das Vorkommen der Eisensteine im Westfälischen Steinkolengebirge. *Z.* f. B. H. u. S.-Wesen im preuss. St., 1868, Vol. XVII, p. 426. W. Runge: 'Das Ruhr-Steinkohlenbecken.' Berlin, 1892, pp. 70-73.

participates in all the flexures and faults to which the entire formation has been subjected.

II. Clay Ironstone Measures.

These ores accompany the coal beds, especially in the lowest measures, lying either above or below or forming partings, which may replace the coal seam altogether. This clay ironstone is very rich in carbon, and contains as high as 39% of iron (up to 60% roasted). In the fifties and sixties large quantities of this black band ore were produced. About fourteen different layers, varying up to a meter in thickness, have yielded workable ores in the past. The ores are sometimes so rich in phosphorus that they are used for the production of superphosphates.

III. Spherosiderites.

Spherosiderite concretions containing up to 45% of iron are not infrequently found in the clay slates and coal seams of the lower measures, and sometimes unite and form extensive beds of clay iron ore.

The production of iron ores in the Ruhr coal district reached, according to Baumler, 167,609 tons in 1890.

2. *Carbonaceous Iron Ores of Upper Silesia and Saxony.*

Workable ore beds also occur in the coal basin of upper Silesia.[1] Spherosiderites within the clay slates are especially common, and in rare cases, as in the upper coal bed of the Saara measure, and at Czernitz, bituminous iron ores (black band ores) have also been developed. The spherosiderites form large lenticular and nodular masses, which may extend along the strike for a few meters. Fig. 46 illustrates this occurrence.

The largest production in the sixties took place at Antonienhutte, Friedenshütte and Ruda, at Zalenze, Janow, Orzesze, Dubensko and Ornontowitz.

At many points, as at Zalenze, it has been noted that the spherosiderites occur especially above the flat depressions in the coal measures.

In 1900 upper Silesia produced 7,147 tons of carbonaceous iron ore. In the Zwickau area district[2] of Saxony spherosiderites and carbonaceous iron ore were for a while produced along with the coal.

Deposits of the first named ore were mined from especial pits in the region

[1] F. Römer: 'Geologie von Oberschlesien.' 1870. Appendix by W. Runge, p. 533.

[2] H. Mietzsch: 'Erläuterungen zu Section Zwickau der geol. Spez.-K.,' 1877. p. 11.

of the Russkohlen measures and also from the Segen Gottes measures (lower reef) within the clay slates. Carbonaceous iron ore, found, for example, in the lower part of the measure at the Bahnhof shaft at Zwickau, formed a stratum 0.2 m. (0.6 ft.) in thickness, containing veins of zincblende, but possessing little extent.

At the coal mines of Kastner & Co., in the Reinsdorff, near Zwickau, a spathic iron ore deposit up to 0.8 m. (2.6 ft.) thick has recently[1] been discovered under the earthy coal measures. The spherosiderite found between the third and fourth measures of the Hilfe Gottes shaft, near Zwickau, contained the rare mineral *whewellite,* besides zincblende and iron pyrite in its fissures.

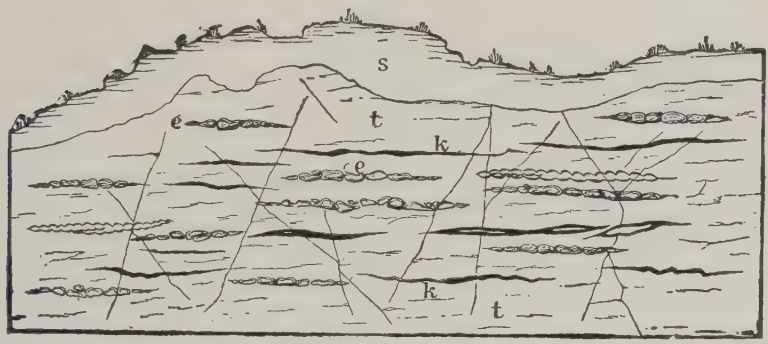

Fig. 46.—Section through the carbonaceous clay slate at Janow. (F. Römer.)
s, sand; t, clay slate; e, spherosiderite lenses; k, coal pockets and carbonized sigillaria trunks.

Spathic iron ore and brown hematite are also found in the Carboniferous formations of the eastern Austrian Alps, as at Turrach, southwest of Murau, where 5,327.3 tons of brown hematite were produced in 1898.

3. *Carbonaceous Iron Ores of Great Britain.*

Great Britain is rich in deposits of this kind. In southern Wales[2] most of the ironstones are found in the lower divisions of the productive coal measures. Many of the numerous blackband beds of that region seem to be continuous throughout the entire district, as, for example, the Three-quarter Balls measure. The main production in Wales comes from Ebbw Vale,

[1] *Jahrb.* f. B. u. H. in Sachsen, 1899, p. 141.
[2] Phillips-Louis. 'Ore Deposits.' 1896, pp. 285, 323.

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Blaenafon, Pontypool, Abercarn and Dowlais. The ore contains 21 to 38% of iron. The production of South Wales in 1880 was 170,000 tons. Important deposits of blackband ironstone also occur in Scotland. The iron ore measures of that country occur, according to H. Louis, in both the upper and the lower Carboniferous formations. The upper Carboniferous contains seven beds of this ore, one of which reaches a thickness of 0.9 m. (2.9 ft.). The lower Carboniferous holds three iron ore beds 0.3 m. thick. These blackband ores contain such an abundance of carbonaceous matter that they burn in the roasting furnaces without the addition of fuel, the residue containing 50 to 70% of iron. Besides these blackband ores, clay ironstone occurs at Bauton, Denny and elsewhere. In 1881 Scotland produced 1,402,700 tons of blackband ore and 1,192,675 tons of clay ironstone. In 1894, however, the total output had dropped to 631,304 tons.

(c) The Iron Ore Formations of the Northern Alps (Probably Permian).

Iron ore deposits occur in the so-called graywacke[1] zone, which lies between the central range of crystalline rocks and the limestone peaks of the Tyrolean Alps on the north, the Salzkammergut of Styria and Austria. Recently, through the labors of M. Vacek, the geologic age and structure of the rocks of this complicated region have been determined, and the true stratigraphic position of these iron ores, hitherto in dispute, has been clearly established. In the area between Enns and Mur the iron ores consist of spathic ironstones and brown hematites with associated slaty, conglomeratic and breccia-like rocks, especially limestone breccias with a sericitic cement, whose fragments are derived from the upper Silurian. Ordinarily the iron ores form the lowest beds, resting unconformably on lower Devonian limestone, as at Eisenerz, or sometimes on still older gneisses. The slates and breccias, which are well developed at Admont, but are quite subordinate in the Eisenerz measures, are often unconformably overlain by lower Triassic Werfener slates. The exact age of the formation is still unknown, but is either Permian or between that and upper Devonian.

A continuous series of such iron ore deposits is always found on the unconformity at the base of the lower Triassic formation, from Schwatz and Pillersee in Tyrol, across Dienten, Flachau and Werfen in Salzburg, Lietzen, Admont in the Radmer, Eisenerz, at Feistereck, on the Veitsch and Neu-

[1] "Graywacke is an old name of loose signification, but chiefly applied to metamorphosed shaly sandstones that yield a tough irregularly breaking rock different from slate on the one hand and from quartzite on the other."—J. F. Kemp, 'Handbook of Rocks,' pp. 140.

berg in Styria as far as Reichenau in lower Austria. The strata unquestionably attain their greatest development at Erzberg, near Eisenerz.

The Erzberg Near Eisenerz.

Eisenerz[1] lies on the northwest side of the Prebichel Pass, which connects the valley leading to the Enns near Hieflau with the valley discharging into the Mur at Leoben. The district is in a depression of the high mountain range lying between the lower Tauern on the west and the Hochschwab on the east.

The Erzberg itself is an almost isolated cone 1,537 m. (5,131 ft.) high, whose summit affords a magnificent panorama. The upper part of the cone is formed of an enormous thickening of an iron ore bed, which, according to M. Vacek, rests unconformably on lower Devonian limestone, carrying *Bronteus palifer* Beyr, etc. This unconformity is well exposed in the limestone cliffs, which show the underlying rock projecting into the ore deposit. The accompanying cross-section after M. Vacek (Fig. 47) gives a clear representation of the structural conditions. It shows that the lower Devonian Sauberg limestones underlying the ore beds rest unconformably on the so-called granular graywackes of Eisenerz, rocks which, according to Vacek, are really gneisses. In the northeastern part of the Erzberg, in the Söbberhaggen, the ore lies immediately above this graywacke-like gneiss. It should be noted that in the eastern part of the district, near the Barbara chapel, the Erzberg ore deposit is unconformably overlain by the Werfener slates which dip north. These slates ordinarily begin with a breccia formation, seen in the Peter Tunner adit. In the western part of the Erzberg, however, through which the profile is drawn, these lower Triassic Werfener strata have been removed by denudation, and the ores outcrop.

According to F. v. Hauers the ore bed is sometimes as much as 125 m. (410 ft.) in thickness. A part of the deposit shows, however, a large proportion of ankerite, and all transitions from siderite and ankerite to ordinary limestone, and in several cases the deposits consist entirely of "Rohwande," as the ankerite ore is called.

The ore averages 40% of iron. The spathic iron ore is not entirely free

[1] F. Ritter von Ferro: Innerberger Hauptgewerkschaft. *Tunners mont. Jahrb.*, Vol. III, 1845, p. 197. A. von Schouppe: 'Erzberg bei Eisenerz.' *Jahrb.* d. k. k. geol. Reichsanst. 1854, p. 396. A. Miller von Hauenfels: 'Die steiermärkischen Bergbaue,' in 'Ein treues Bild des Herzogth, Steiermark,' Vienna, 1859, p. 16. D. Stur: 'Vorkommen obersilur. Petrefacten am Erzberg.' *Jahrb.* d. k. k. geol. Reichsanst., 1865, p. 267. F. von Hauer: 'Geologie der österr. Monarchie.' 1875, p. 223. M. Vacek: 'Ueber den geologischen Bau der Centralalpen zwischen Enns und Mur.' *Verh.* d. k. k. geol. Reichsanst., 1886, p. 71. Also 'Skizze eines geologischen Profiles durch den steierischen Erzberg.' *Jahrb.* d. k. k. geol. Reichsanst., 1900, Vol. L., p. 23. (The foregoing represent the most important publications about Eisenerz.)

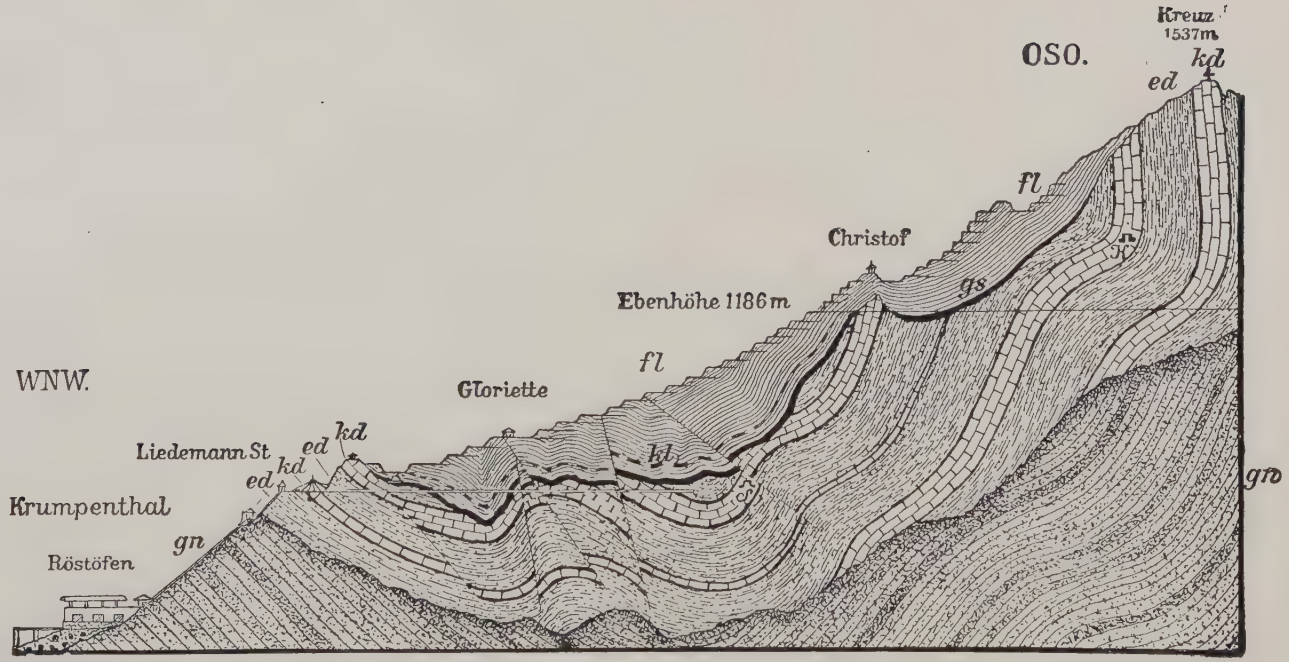


Fig. 47.—Profile through the Erzberg at Eisenerz. (M. Vacek.)
gn, gneissoid rocks (''Eisenerz graywacke''); kd, lower Devonian limestone; ed, lower Devonian iron ores and ''Rohwande''; fl, ''Flinze'' spathic iron ore of the Perman (?); kl, impure calcareous layer; gs, basal shale of the Permian (?).

from sulphides, as pyrite and chalcopyrite occur in scattered grains, and rarely it holds small streaks of cinnabar. The phosphorus content hardly reaches 0.01%.

The mining industry of Eisenerz began in Roman time. Documents extending back to the year 712 A. D. are said to have been formerly in existence. At any rate Tacitus and other classic writers mention "Noric iron." The mining is carried on both by open cuts rising in terraces along the slope, and by underground work.

The production in 1898 was as follows:

Innerberger Gewerkschaft, near Eisenerz, 923,454.2 tons of spathic iron ore; Vordernberger Gewerkschaft (Oesterreichische Alpine-Montangesellschaft), 75,038 tons; Veitsch mine, 152.5 tons; Olimie mine, near Windisch-Landsberg, 965 tons.

(d) Permian Spherosiderites.

Clay ironstone concretions occur in the *Acanthodes* slates of the Lebach formation of the lower Rothliegende at Saarbrucken. These ellipsoidal concretions often enclose organic remains, such as *Archegosaurus* and *Walchia*. They are called "Knopfstrich."

At Goldlauter, near Suhl, in Thuringia, the dark clay slates of the Rothliegende carry nodular concretions consisting of alternate shells of slaty brown spar, arsenopyrite and pyrite, and often containing a central core of copper pyrite, gray copper and native silver.[1]

(e) Sedimentary Ironstones of Jurassic Age.

1. *Liassic Iron Ores.*

Germany possesses true ironstone measures in many of the Jurassic formations[2]. The Lias, for example, contains four beds of finely oolitic, usually porous limonite, with an aggregate thickness at Bundheim, near Harzburg, of 4 m. (13.1 ft.) (zone of *Amm. Bucklandi*). The output of the Friederike mine at that place averaged 44% of iron. The ironstone measures of Willershausen, Calefeld and Oldershausen in Hanover also belong to the Lias (zone of *Amm. Jamesoni* and *Amm. Ibex*).

The Middle Lias of England also contains iron ores mined in the Cleveland district. The principal bed extends over an area of 350 square miles,

[1] B. von Cotta: 'Erzlagerstätten,' II, 1861, p. 72.

[2] J. Haniel: 'Ueber das Auftreten und die Verbreitung des Eisensteins in den Jura-Ablagerungen Deutschlands.' *Z.* d. Deutsch. geol. Ges., Vol. XXVI, 1874, pp. 59–118.

and is workable for one-fifth of this area[1]. The ores average 30% of iron and 1.5% of phosphoric acid.

2. *Iron Ores of the Dogger Formation of the Jura.*

The most widely distributed iron ore beds of Jurassic age are those of the Dogger formation. The Minette ore beds belong to this formation.

Oolitic Iron Ores (Minettes) of Luxemberg and Lorraine[2].

The Minette beds belong to the lower Dogger formation, which is characterized by the fossils *Harpoceras Murchisonae* and *Harpoceras Opalinum*. The accompanying profile (Fig. 48), after W. Branco, gives the detailed classification of the various beds of the Minette horizon.

The Minette measures occur mainly throughout the frontier region between Luxemberg, German Lorraine and French Lorraine, in a strip of 100 km. (60 miles) long, 18 km. (10.8 miles) wide, west of the Moselle, the portion belonging to Germany being 60 km. (36 miles) long and 12 km. (7.2 miles) wide.

The most important mines of Luxemberg are at Beles, Esch and Rümlingen; of Lorraine (German) Ottingen, Tillots, Neufchef, Hayingen, Moyeuvre, Rosslingen, Maringen, Vaux, Chabonniere, Varraines, Novéant and Arry; in France, Longwy and Briey. This plateau-like area is traversed by long cliffs running north and south, which show at the foot a gently sloping area of Liassic beds, and at the summit an abrupt slope cut in oolitic limestone (Dogger). At the boundary between the gentle slope and the steep escarpment the outcrops of the Minette measures are usually found. In Luxemberg, the valley of the Alzette divides the formation into two flat basins. The different beds do not always extend uniformly throughout both basins, but show the distribution indicated in the diagram (Fig. 49, after Van Werveke), which also applies to other areas.

[1] J. D. Kendall: 'The Iron Ores of Great Britain,' 1893. Cited by Phillips-Louis, 'Ore Deposits,' p. 44.

[2] E. Giesler: 'Das oolithische Eisensteinvorkommen in Deutsch-Lothringen.' *Z.* f. B. H. u. S.-Wesen im preuss. St. Vol. XXIII, 1875, pp. 9–41. W. Branco: 'Der untere Dogger Deutsch-Lothringens.' Strassburg, 1879. Van Werveke: 'Erläuterungen zur geologischen Uebersichtskarte des westlichen Deutsch-Lothringen.' Strassburg, 1887, pp. 83–99. L. Hoffmann: *Stahl u. Eisen*, 1896, Nos. 23 and 24. Schrödter: *Zeit. f. Prak. Geol.*, 1897, p. 296. W. Kohlmann: 'Die Minetteformation nördlich der Fentsch.' *Stahl u. Eisen*, July, 1898. *Zeit. f. Prak. Geol.*, 1898, p. 363. 'Uebersichts-karte der Eisenerzfelder des westlichen Deutsch-Lothringen.' 3d edition, Strassburg, 1899. F. Greven: 'Das Vorkom. der Oolith Eisenerz im südlichen Deutsch-Lothringen,' *Stahl u. Eisen*, 1898, No. 1. H. Ansel: 'Die Oolith. Eisenerzform. Deutsch-Lothringens.' *Zeit. f. Prak. Geol.*, 1901, pp. 81–94. L. von Werveke: 'Ueber die Zusammensetzung und Entstehung der Minetten.' Reviewed *Zeit. f. Prak. Geol.*, 1901, pp. 396–403.

In German Lorraine the following strata are distinguished from below upward:

The *black* bed, the most extensive, but so siliceous that it is only mined

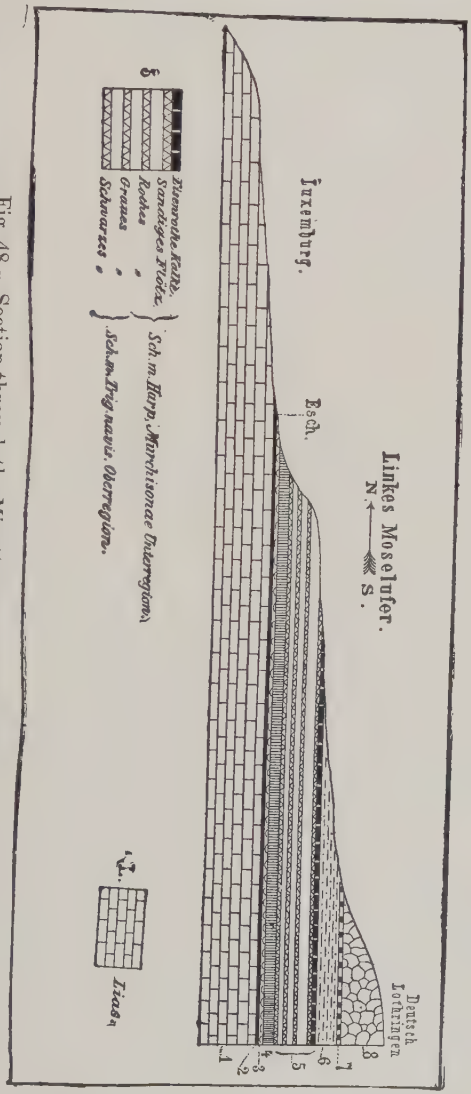


Fig. 48.—Section through the Minette measures at Esch. (W. Branco.)

8, calcareous layer with *Harpoceras Humphriesianum*; 7, calcareous layer with *Harpoceras Sowerbyi*; 6, marl with *Harpoceras Marchisonæ*; 5, the Minette measure group (see legend); 4, sandstone with *Trigonia Navis*; 2 and 3, upper and lower clays with *Harpoceras Striatulum*; 1, Lias (micaceous marl).

for a flux for the calcareous ores; 1.2 to 3.9 m. (4 ft. to 13 ft.) thick.

The *brown* bed, whose ore is also siliceous, is separated from the preceding by a marly parting 0 to 4 m. (0 to 13.1 ft.) thick.

The *gray* bed, whose nearly uniform thickness of 5 to 6 m. (16.4 ft. to 19.6 ft.) and excellent quality make it the most important, is accompanied by a yellow bed and carries as fossils *Gryphaera ferruginea, Amm. radians,* etc.

The *red limy bed,* the most valuable of the Luxemberg beds, has a maximum thickness of 8 m. (26.2 ft.), though seldom workable in German Lorraine; its lower layers contain *Amm. Murchisonae* and *Pholadomya reticulata.*

The *red sandy bed,* the thickest of all, being sometimes 13 m. (42 ft.) through; but it contains a great deal of quartz in sandy grains.

The following table, by H. Ansel, gives a summary of the average chemical composition of the different beds, only the technically important elements being given:

Bed.	Fe	C_aO	SiO_2	Al_2O_3	P_2O_5	MgO
Black	30	6	24.5	10	1.4	1.5
Brown	34.3	8.6	16.6	6.5	....	2
Gray	39	8.0	7.5	6	1.7	1.6
Yellow	36	12.3	8.5	3	1.3	1.4
Red (limy)	40	9.5	7.5	5	1.8	1.2
Red (siliceous)	31	5.3	33.6	4.2	1.6	9.5

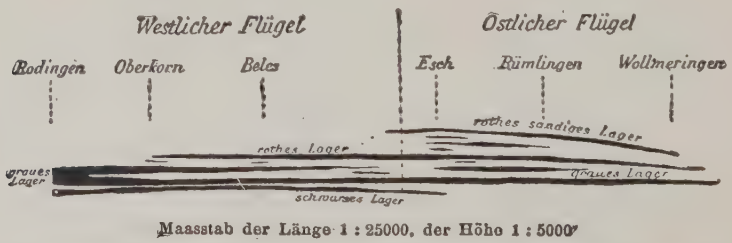


Fig. 49.—Diagram showing the development of the Minette measures. (Van Werveke.)

The Minettes of Lorraine consist of oolitic grains, mostly less than 0.25 millimeter in diameter, and consist essentially of ferric hydrate. The grains have a smooth surface and are bound together by a cement that is usually calcareous, but is rarely clayey or siliceous from the presence of interspersed quartz grains. In thin section under the microscope the oolites show very distinct concentric shells about one or sometimes two cores. In rare cases organic remains are found to have served as a nucleus, consisting of fragments of echinoderms, segments of crinoid stems or small gastropods. On the other hand, the grains sometimes contain scales of an indeter-

minate green iron silicate, and the presence of a microscopically fine siliceous skeleton enclosed in the limonite oolites indicates a former greater abundance of the iron silicates. More frequently scales are found of a chamosite-like mineral in the cementing material. In some beds iron spar is present in considerable amount, constituting as much as 60% of the ore of the lowest bed. Pyrite is also occasionally present, particularly in the black bed ores. In some Minettes the green mineral of the cement and the limonite of the oolites are both replaced by magnetite. Not infrequently the ores contain calcspar casts of large fossils, and sometimes carbonized wood remains.

The beds of the ore-carrying Dogger formation are inclined gently westward. The structural feature of the greatest importance to the mining industry is the faulting, and there are numerous displacements along northeast fissures such as the fault of Deutsch-Oth, with a throw of 120 m. (393 ft.) and the fault of Gorze-Metz, known for a distance of 85 km. (51 miles).

A valuable summary of our present knowledge concerning the genesis of the Minettes is given by L. van Werveke (1901). According to him most authors agree that the oolitic iron ores of Lorraine were deposited on the bottom of a shallow coastal sea. "The iron was brought from the land to the sea by brooks and rivers, and was precipitated in very diverse forms as silicate (looking like glauconite), also as carbonate, sulphide and sesquioxide in the upper strata, possibly also as ferric hydrate." (L. Van Werveke.) The cement in part is a mechanical sediment.

Another theory less generally accepted is advanced by Villain. According to him, the iron-bearing solutions were carried directly to the sea by thermal springs issuing from fissures in the ocean's bed. For the deposits of German Lorraine at any rate the agency of such "failles hourricieres" (feeding faults) seems to be untenable. A metasomatic origin of the Minettes seems to be altogether out of the question.

The production of Minette ores in the French department of Meurthe-et-Moselle was 2,630,311 tons in 1890. In German Lorraine 5,955,351 tons of iron ore were produced in 1899. The stock of ore still available is very large, being estimated at two thousand million tons in the German areas.

3. *The Iron Ores of the Dogger Formation of Wurtemburg, Upper Silesia and Switzerland.*

The iron ore measures of Wurtemburg belong to the Jura (zone of *Amm. Murchisonae*), especially in the region of Wasseralfingen and Aalen.

The sedimentary sequence at that locality is, according to Schuler,[1] as follows:

Sandstones, sandy slates and clay sandstones overlying the measure; upper ironstone bed 1.1 m. (3.6 ft.); sandstones and sandy slates 10 m. (32.8 ft.); lower ironstone bed, 1.6 m. (5.2 ft.); so-called stalhstein and sandy hard limestone .02 m. (4-5 in.); sandstones and clay sandstones underlying the above.

The ores of Wasseralfingen and Aalen are oolitic red and brown hematites, containing about 40% of iron. They not infrequently enclose fossils, especially *Amm. Murchisonae, Avicula elegans* and *laevigata, Venulites aalensis, Pecten demissus.* The production at the present day is inconsiderable.

The Dogger formation of upper Silesia also encloses iron ore in a zone characterized by fossils of *Ammonites parkinsoni,* according to F. Romer[2]. At Bodzanowitz, Wichrow and Sternalitz, southeast of Landsberg, a sandy upper bed and a purer lower bed of spherosiderite have long been mined for the Malapane furnaces. Similar occurrences are mined in Poland at Kostrzyn and Przystayn, as well as at Stara Kuznica.

In the iron mines of the Kleine Windgalle, in the canton of Uri (Switzerland) oolitic iron ores belonging to the Dogger are seen altered by dynamo-metamorphism; the hematite concretions have been pressed into flat lenses and iron silicates and magnetite crystals have been formed[3].

(f) The Eocene Iron Oolites of Kessenberg and Sonthofen, Bavaria.

In the Nummulitic sandstone[4] of Kressenberg and Sonthofen in upper Bavaria three groups of oolitic limonite beds are intercalated, which have been steeply upraised along with the other strata and dislocated by many faults. The local miner gives the name lodes (gange) to these measures, the principal one of which attains a thickness of two meters. Besides glauconite, the ore contains numerous quartz grains, and thus gradually passes into an iron sandstone. The most abundant fossil of the measure is *Conoclypeus conoideus* Ag., whose shell is entirely filled with oolitic brown hematite.

(g) Bog Iron Ores and Lake Ores.

This class of the iron ore deposits is of especial interest because the beds

[1] J. Haniel: 'Ueber das Auftreten und die Verbreitung des Eisensteins in den Jura-Ablagerungen Deutschlands.' *Z.* d. Deutsch. geol. Ges., Vol. XXVI, 1874, p. 97.

[2] F. Römer: 'Geologie von Oberschlesien,' 1870, p. 210.

[3] A. Heim: 'Mechanismus der Gebirgsbildung,' Vol. I, p. 62, Vol. II, p. 98.

[4] C. W. Gümbel: 'Geogn. Beschr. des bayerischen Alpengebirges,' 1861, p. 647. O. M. Reis: 'Zur Geologie der Eisenoolithe führenden Eocänschichten am Kressenberge in Bayern.' *Geogn. Jahresh.*, Munich, 1897.

are now forming, and the process of ore formation is taking place, as it were, before our eyes; so that we may obtain important information bearing upon the genesis of the older formations. In addition to this geologic importance, they have recently acquired an economic value, since it is now possible to smelt these high phosphorus ores, and at the same time to recover the phosphoric acid in them, and return it to Nature as the fertilizer known in Europe as Thomas meal.

Character and Mode of Deposition of Bog and of Lacustrine Iron Ores.[1]

Bog iron ore, also called swamp ore, meadow ore and bog ore, is yellowish, brownish or blackish brown limonite, with resinous luster on fresh fractures, always highly porous and cavernous, often slag-like and hard, sometimes ochrous, loose, earthy and mingled with many other substances. The ores contain hydrated iron silicate (a gelatinizing basic iron-silicate), also iron phosphates, crenates, ulmates and humates. The ores contain between 20 and 60% of Fe_2O_3. The phosphoric acid content rises as high as 10%. There is also a mechanical admixture of sand grains and clayey particles.

Chemical Analyses of Lacustrine and Bog Ores[2].

	I.	II.	III.	IV.
Iron oxide	62.92	67.46	51.10	62.57
Manganese oxide	4.18	3.19		5.58
Silica	8.12	7.00	9.20	12.64
Phosphoric acid	3.44	0.67	10.99	0.48
Sulphuric acid	.....	3.07	.....	0.07
Alumina	4.60	.....	0.41	3.58
Lime	.....	0.90	.....	1.37
Magnesia	.....	.....	.....	0.19
Water	18.40	17.00	28.80	13.53
	101.66	99.29	100.50	99.82

I. Bog ore from Schleswig (Pfaff).

II. From Auer near Moritzburg in Saxony (Bischof).

III. From Leipzig (Erdmann).

IV. Average of thirty analyses of Swedish lake ores (Svanberg).

Deposits of bog iron ore are found where surface water stagnates in the shallow depressions of flat lands, especially in the vicinity of sluggish streams whose waters are colored brown by dissolved humous acids or humic salts,

[1] F. Senft: 'Die Torf und Limonitbildungen,' etc. Leipzig, 1862. F. M. Stapff: 'Ueber die Entstehung der Seeerze.' *Z.* d. Deutsch. geol. Ges., Vol. XVIII, 1866, pp. 86-173. A. W. Cronquist: 'Om sjömalmsfyndigheten,' etc. *Geol. För. Förh.* No. 65, Vol. V, 1880, p. 402. Hj. Sjögren: 'Om de svenska jernmalmens genesis.' *Geol. För. Förh.* Vol. XIII, 1891, p. 373. R. Klebs: 'Das Sumpferz.' Vortrag, Königsberg, 1896.

[2] F. Zirkel. 'Petrographie.' III, p. 574.

and in the moor and meadow bottoms of the lowlands of northern Europe, Asia and North America. The Saxon and Prussian parts of lower Lusatia, Brandenburg, Mecklenburg, Pomerania, Prussia, Masuria, Poland, European Russia, Holland, Finland and Sweden are rich in bog iron ores. In North America the Three River district, Province of Quebec, contains a typical deposit, in which mining was begun as early as 1730. Sometimes ores of this kind are also found on high plateaus of the mountains of central Germany.

These deposits rarely attain a thickness of over a meter. For the most part they show no stratification. Often they form isolated lumps, cakes or slabs, which exert an unfavorable influence on the immediately overlying field or meadow land, because they shut off water and air from the deeper layers of soil and hence are disliked by the farmers.

These iron ores have been worked since the earliest period known; hence Linné called them Tophus Tubalcaini, because Tubal Cain, the first iron worker, is supposed to have manufactured iron out of them.

The Lake ores (Sjömalmer of the Swedes) are somewhat different in quality and quite different in their deposition. They are found at the bottom of innumerable lakes in the Swedish Province of Småland, Ostergötland, Dalarne, Herjeådalen, Jämtland and Norrland; in Finland, European Russia and in Canada. They are mostly found on a sandy bottom at a distance of about ten meters from the shore and up to a depth of about 10 m. (32.8 ft.). The deposits are usually thin, rarely reaching 0.5 m. (1.6 ft.) in thickness, but as they may be obtained by simple dredging, they are worked even if but 10 cm. to 15 cm. (4 to 6 inches) thick. The supply is renewed in about fifteen to thirty years. "Estque thesaurus hic perennis et inexhaustus" (this is a perpetual and inexhaustible treasure), says Swedenborg of these lake ores of his home. The ore in the lakes does not form a continuous sheet, but occurs in round or elongated patches, whose direction and arrangement is evidently determined by the currents due to streams entering the lakes, since the ore beds are in shallows covered by an abundant growth of water plants, while the currents supply sand and mud. Lake ores sometimes occur in rivers, as, for example, in the channels connecting Swedish lakes, but the deposits only occur in quiet water found on the convex side of curves and not in the rapid current. Thus we have an example, showing how streaks or linear masses of ore of fairly uniform character may be formed with and as part of a series of sediments.

The formation of these lake ores is accomplished in several stages, each characterized by different material. In the first stage the iron oxide settling on the bottom, at first as a light ochrous mud, gradually hardens into crusts, having the luster, color and hardness of true ore. This mud has a black-

ish gray, brownish or greenish color, and is filled with vegetal débris. Exposed to the air, it dries to a gray or yellow powder. It is rich in gelatinous silica and contains numerous algae. On hardening, the masses of mud form either compact lumps (rusor), small or large discs and balls, or else they encrust roots, portions of trunks and branches of plants and animal remains, such as beetles and worm tubes, Phryganid quivers and the like. All of these deposits consist partly of hard, brown resinous-lustrous and partly loose, yellowish or brownish ochrous ore. In the spherical masses concentric shells of hard and loose ore alternate, often about a nucleal grain of sand or a vegetal remnant. The Swedish miners class the ores according to size and shape of these concretions as krutmalm (powder ore), aertmalm (pea ore), bonmalm (bean ore), penningmalm (penny ore) and skraggmalm (fragment ore). The fresh and soft unhardened ores often contain the phosphoric acid in the form of earthy vivianite, a blue iron ore, which may be greatly concentrated at certain spots. A good deal of manganese ore, probably in the form of wad, is also frequently mixed with the pulverulent lake ores of Sweden.

General Remarks on the Origin of Lake and Bog Ores.

It is certain that the deposition of all these ores took place from very dilute iron solutions, belonging to either the groundwater or that of lakes and rivers. The origin of the iron is apparent, for almost all rocks contain iron compounds, which, under certain circumstances, are soluble. If rare metals are present in the ores, one must look for older primary deposits of sulphide ores, whose decomposition furnished the material for such solutions. Thus in the Lake ores of Sweden there are found traces of copper, nickel, cobalt and zinc, which unquestionably are derived from decomposed pyrites of older deposits, which are abundant in the vicinity. Thus a bog ore from the Tertiary trough between Grochau and Briesnitz, which lies southwest of the nickel ore deposit of Frankenstein in Silesia, was found to contain:

Nickel	3.5%
Cobalt	1.3
Copper	0.1

Next follows the question, What was the nature of the solutions? The following are the chief solvents:

1. Sulphuric acid formed by the decomposition of iron-bearing sulphides.

2. Carbonic acid supplied by the air and by decaying organisms, and to some extent by the living animals. This enables it to attack various silicates.

3. Organic acids also play a part. These are, moreover, transformed into carbonic acid by oxidation, when vegetable masses decompose. In the presence of decaying vegetable matter, deprived of an adequate oxygen supply, iron sesquioxide is reduced to ferrous oxide, which forms soluble double salts, with humous acids and ammonium.

The precipitation of iron from these dilute solutions may take place in various ways.

In solutions of iron sulphate, the mere addition of ammonium humate, which is always present in the brown waters of peaty areas, effects a precipitation of iron oxide and later on of ferric hydrate.

From carbonated solutions the iron is precipitated as ferric hydrate by the escape of carbonic acid into the air, or by its absorption by plant cells. The deposition of iron carbonate is only possible when the air is excluded or in the presence of organic matter, which seems to harmonize with the known facts concerning spherosiderite and blackband ores.

From humates and other organic compounds the ferric hydrate is precipitated by the oxidation of the humous acids and their decomposition into carbonic acid and water. Here, too, the plant cell accelerates this process by furnishing oxygen. Lastly, by the mingling of iron humates and sulphates, the sulphuric acid, which kept the iron sesquioxide in solution, unites with ammonium, and iron is precipitated as hydroxide or as ferric humate.

In this action, the life processes of plants take a part, entirely independent of any products of plant decay. According to Ehrenberg, the algæ, especially the so-called iron algæ, *Galionella ferruginea*, Ehrenb., are active ore precipitants, coating their cell walls with ferric hydrate and opaline silica. This alga is abundant on the sea bottoms. According to the recent works of Molisch and Winogradsky, these and most other supposed algæ are ciliated bacteria of different kinds, especially *Leptothrix ochracea*.[1]

The silica of these ores may originally have been held in solution as alkaline silicates, which are supposed to be decomposed by carbonic acid. This silica is precipitated simultaneously with the ferric hydrate. The phosphoric acid was certainly present as ammonium phosphate and is precipitated at first as iron phosphate and as calcium phosphate in calcareous ores.

The further speculations which these processes suggest as to the genesis of the older stratified iron ore beds are given on page 81.

We saw that in the case of lake ores the deposition took place quite slowly. This process is more rapid where the drainage from the gossan (which see) of a large pyrite deposit is carried into a lake basin, or into the sea, or

[1] Weed: 'Geological Work of Plants,' *Am. Geol.*, June, 1894. Walther: 'Einleitung in die Geologie.' Jena, 1893-4, p. 655.

where mining operations produce an inflow of great quantities of iron-bearing mine waters. Thus the bottom of Lake Tisken, near Falun, is covered with a layer of ocher-mud several meters thick that has been furnished by the neighboring pyrite stock. The bed of the Rio Tinto carries ocher-mud and diatoms derived from the waters of the copper mines as far as Palos in Huelva Bay. That this was the case even before mining began at that locality is proved by the deposit of iron ore on the Mesa de los Pinos and the Cerro de las Vacas (see Figure 50). These limonite deposits were formed in a bog which was afterwards dissected by the river. The ironstones contain plant remains of the same character as the present flora. Slabs of this ore were used by the Romans for tombstones.[1]

The deposition of iron ore is also rapid in places where iron-bearing mineral waters come to the surface in swampy hollows. An interesting case is

Fig. 50.—Profile through a part of the Rio Tinto ore field. (A. Phillips.)
s, clay slate; p, porphyry; k, copper ore bed; e, Pleistocene iron ores.

the extensive mineral marsh in the Soos near Franzensbad, described by O. Bieber.[2] The marshy beds of that locality are strongly impregnated by the waters of mineral springs, carrying sodium sulphate, magnesium sulphate, iron sulphate and other salts, and are overlain in many cases by whole beds of bog iron ore, blue iron ore and iron ocher. East of the sour spring called Polterer or Kaiserquelle, for example, we find the following section:

(1) Mineral bog 3 to 5 meters; (2) bog iron ore 0.3 m.; (3) blue iron ore (vivianite) 0.5; (4) iron ocher 0.3 to 0.5 meters.

The occasional occurrence of pyrite and marcasite in the mineral moor is noted later on.

(h) Recent Iron Ores of Marine Origin.

Aside from the deposits of iron ocher above mentioned, which must be forming at present in Huelva Bay, and perhaps to a less extent on some other portions of the coast, we do not know of any really recent iron ores found on the sea bottom. However, deep sea investigations have proved the very wide distribution of a highly ferruginous sediment, the glauconite

[1] H. Louis: 'Ore Deposits.' Second edition. 1896, p. 41.
[2] O. Bieber: 'Das mineralmoor der Soos,' Marburg, 1887, p. 29.

ooze.[1] It is probable that certain older iron ore deposits may be sediments of this kind altered by subsequent metamorphosism and modified perhaps by a subsequent concentration of the iron compounds.

According to J. Walther[2] the S. S. Tuscarora found off the coast of California, at a depth of 180 to 730 meters, black sands consisting almost entirely of dark green glauconite grains 0.6 millimeter in size. Glauconite sand of such purity is rare, while glauconitic sediments have been shown by the Challenger and other expeditions to be very widely distributed at depths of 590 to 5,395 ft. Phosphate concretions also occur associated with the glauconite. The amount of lime may reach 56%, and increases with the distance from the land. These masses of green mud contain an insoluble residue of 44% or more, consisting of siliceous shells and portions of skeletons of organisms, as well as of granules of quartz and very diverse rock silicates. Towards the middle of the ocean basin these formations are wanting.

The following analyses of recent glauconite sediments are taken from the work, 'The Voyage of H. M. S. Challenger; Report on the Deep-Sea Deposits,' p. 387:

Station.	Depth in fathoms.	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	H_2O	Total.
164 B	410	56.62	12.54	15.63	1.18	Trace	1.69	2.49	2.52	0.90	6.84	100.41
164 B	410	50.85	8.92	24.40	1.66	Trace	1.26	3.13	4.21	0.25	5.55	100.23
164 B	410	51.80	8.67	24.21	1.54	Trace	1.27	3.04	3.86	0.25	5.68	100.32
164 B	410	55.17	8.12	21.59	1.95	Trace	1.34	2.83	3.36	0.27	5.76	100.39
185 B	155	27.74	13.02	39.93	1.76	Trace	1.19	4.62	0.95	0.62	10.85	100.68

II. SEDIMENTARY DEPOSITS OF MANGANESE ORE.

A. Within the Crystalline Schists.

1. *Manganese Ore Deposits of Långban, Sweden.*[3]

This mining district lies north of Philipstad, in Vermland, between Lake Långban on the east and Hytt Lake on the west. The deposits are associated with a band of dolomite, 4 km. (2.6 miles), with north-south course and west dip. This dolomite is intercalated in granulite,[4] that is,

[1] The manganiferous ironstone concretions of the deep sea are spoken of later. See Gümbel 'Ueber die Natur und Bildungsweise des Glaukonits.' *Sitz* der K. Ak. Munich, 1886.

[2] J. Walther: 'Einleitung in die Geologie.' Jena, 1893-4, pp. 880-882.

[3] *Zeit. f. Prak. Geol.*, 1899, pt. I.

[4] Törnebohm: 'Ofverblick öfver Bergbyggnaden inom Filipstads Bergslag,' 1877. Nordenström's *Katalog*, p. 38.

a fine-grained biotite gneiss poor in mica, forming an island-like mass in a great area of granite. Dioritic rocks occur on the east.

There are six main deposits, besides many small ones of very irregular shape and having an approximately lineal distribution. The deposits are ordinarily considerably enlarged near their base and thus approach close to one another. They do not consist of workable ore throughout, but sometimes wedge out and are replaced by dolomite or a pyroxene skarn containing scattered streaks of ore.

The Långban dolomite contains about 20% of magnesia and is of granular-crystalline structure. While it is white when fresh and unaltered, it usually turns brown upon exposure to the air, owing to the decomposition of finely interspersed manganese minerals. The ores are divided into iron ores and manganese ores. The former consist mainly of specular hematite and, to a smaller extent, of magnetic iron ores. The manganese ores are mainly braunite and hausmannite in dolomitic matrix. Furthermore, a great number of other manganese minerals appear as rock constituents, the commonest being rhodonite, tephroite, schefferite (a lime-manganese-pyroxene with 8 to 10% of MnO), and richterite (a soda hornblende with 8 to 11% MnO). Not infrequently large bunches of rose quartz and of red, ferruginous quartz are found, the latter material being formerly cut up into cups, paper weights, etc. Certain crush zones or shear zones (skölar), traversing the beds, are frequently coated with manganophyllite (a reddish magnesia mica, with up to 20% MnO).

According to H. Tiberg[1] the strata are arranged in the following manner from above downward. (See Fig. 51, which shows too gentle a dip. The numbers below correspond to those in the figure.)

1. Dolomite with lenticular layers of fine-grained gneiss, mostly poor in mica.
2. Thin layer of hornblende-pyroxene-garnet skarn.
3. Magnetic iron ore with melanite (up to 2 meters).
4. Iron ore with nests of ferruginous quartz (up to about 20 meters).
5. Hausmannite in dolomite (to 3 meters).
6. Braunite and hausmannite (up to 20 meters).
7. Thin layer of skarn (schefferite, richterite, tephroite and rhodonite).
8. Footwall dolomite with streaks and layers of fine-grained gneiss.

The most important layer is the manganese deposit, mainly braunite, forming the lower part of the iron bed of the Kollegii mine, a bed which reaches a thickness of 40 m. (131 ft.) and has been followed for a distance of 65 m. (213 ft.) along the strike. The braunite was not recognized until

[1] *Wermlandska Bugmannafören*, 1901. Lately Tiberg ascribes the origin of the deposit to replacement and not sedimentation.

1878, the hausmannite somewhat earlier. The braunite ore contains as high as 45% of manganese, the hausmannite ore up to 47%. The manganese ore is usually sorted into three grades, with 40, 30 and 20% of manganese. The two last named are concentrated to a 54 to 56% product. Most of the ores are used in the production of bessemer steel, as well as in the glass industry.

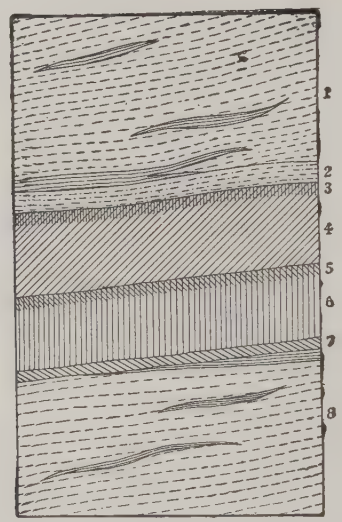


Fig. 51.—Diagrammatic cross-section of Langban ore bed. (H. Tiberg.) (Explanation of figure in text.)

Similar deposits, also associated with dolomite, are found at Pajsberg near Nordmarken, at Jakobsberg and in the Sjö mine in the Oerebro district. It may here be remarked that to the north of Långban, in the Stora Getberg mine, lead, zinc and copper ores occur in the same dolomite intercalation. At Långban itself these ores occur only in subordinate amounts. A remarkable feature of this mine is the association of native lead[1] with hausmannite in fissures in the dolomite. The manganese ore produced in Sweden in 1896 was 2,056 tons.

2. *The Manganese Deposits of Southern Bukowina, Austria.*[2]

The manganese mines of Oberarschitza and Arschitza-Anna occur high up on the slopes of the Eisenthal, 4 km. (2.4 miles) from Jakobeny. The

[1] Igelström in *B. u. H. Z.*, 1816, p. 26.

[2] B. v. Cotta: 'Einlagerungen im Glimmerschiefer der südl. Bukowina,' *B. u. H. Z.*, 1855, No. 39, p. 319. B. Walter: 'Die Erzlagerstätten der südl Bukowina,' *Jahrb.* d. k. k. geol. Reichsanst., Vienna, 1876, pp. 372-382.

ore deposit is 40 m. (133 feet) thick, being enclosed in mica schists that are either horizontal or dip northeast at 30°. Directly beneath is a bed of siliceous schist 6 to 20 m. (19 to 65 ft.) thick, lying upon a hornblende-bearing mica schist. Above the ore is a much decomposed brownish yellow hornblende schist. The ore deposit consists of a mixture of pyrolusite, some hausmannite, brown hematite and quartz. The whole is locally called Schwarzeisenstein (black ironstone). This mass shows distinct bedding, even when decomposed, and in places its primary composition is disclosed, especially at another mine, the Oitza, near the Transylvania boundary. The deposit is in such cases seen to be built up of beds 0.1 to 2 m. thick of manganese silicate (rhodonite), of grayish green to flesh color, and with interspersed portions of rose-colored manganese-spar and quartz, and layers of a yellowish green mica hornblende schist. The transformation of the rhodonite into the more highly oxidized manganese ores and into quartz is traceable step by step through every gradation, the alteration starting along cracks and fissures. The hornblende schist when decomposed furnishes the intermingled brown hematite.

The mines belonging to the Greek Oriental Church yielded 2,063 tons of manganese ore in 1898.

3. *The Manganese-Zinc Deposits of New Jersey.*[1]

Although there is considerable doubt as to the sedimentary origin of this deposit, we include in this section the remarkable ore deposits of Franklin Furnace and Sterling hill in New Jersey, deposits whose exact genesis is still uncertain. It is possible that they do not belong in this group, but to that of contact metamorphic formations.

These deposits occur in a zone of white crystalline limestone, lying upon gneiss and regarded as a metamorphosed Cambrian rock, since it becomes dense away from the deposit, where, according to Nason, it contains Cambrian fossils. If this is correct, the gneiss is probably an altered granite. This hypothesis is further supported by the presence of intrusive masses and veins of a pegmatitic granite, traversing the limestone and carrying augite, hornblende, allanite, zirkon and orangite (Groth). The limestone is exceedingly rich in Mn CO_3 (16.57%) as shown by the brown color of the surface of the weathered rock owing to the formation of MnO_2. In the limestone at its contact with the gneiss, layers of magnetic ore occur, which were formerly worked. At a somewhat higher horizon, however, this marble con-

[1] H. Credner: 'Franklinit und Rothzinkerz im krystallinen Kalkstein,' *B. u. H. Z.*, 1866, p. 29. F. L. Nason: Geol. Survey, New Jersey, 1890, XIV; and 'Franklinite Deposits of Mine Hill,' *Trans.* Am. Inst. Min. Eng., February, 1894. P. Groth: 'Zinkerzlagerstätten von New Jersey,' *Zeit. f. Prak. Geol.*, 1894, p. 230. J. F. Kemp: 'Ore Deposits of U. S.,' 1900, p. 251. Also *Bull.* 210, U. S. Geol. Survey, 1903.

tains two stratiform orebodies, composed of black crystals of franklinite $(ZnFeMn)O,(Fe_2Mn_2)O_3$, zincite (ZnO with up to 8% MnO), willemite and calcite. One of the beds outcrops on Mine hill, near Franklin Furnace; the other on Sterling hill, near Ogdenburg. Between the two hills the valley shows no outcrops. The Franklin Furnace deposit, 12 m. (39 ft. thick), has been the most carefully investigated. As shown by the accompanying section (Fig. 52, after P. Groth), it forms a syncline followed to the southeast by a strongly compressed anticline. After the folding the strata were cut obliquely across by a later dike of diabase.

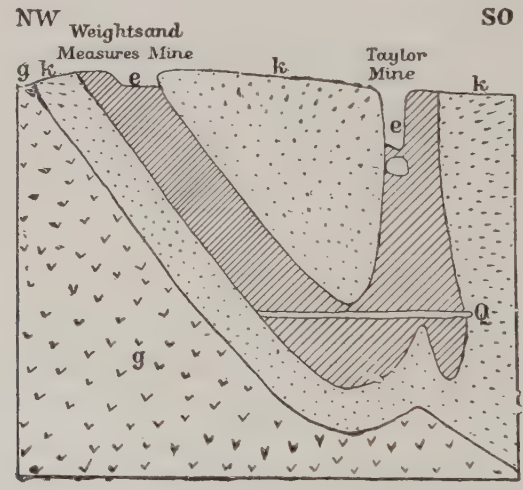


Fig. 52.—Profile through the ore bed of Franklin Furnace. (P. Groth.)
g, gneiss; k, crystalline limestone; e, ore bed; q, cross-cut.

Besides the minerals already mentioned, jeffersonite (a zinc manganese pyroxene), hornblende, tephroite, troostite, fluorite and chloanthite occur in the mine. Near the granite intrusions there are certain other minerals not found elsewhere, namely, garnet, rhodonite, cleiophane (colorless zincblende) and axinite.

4. *Manganese Ore Deposits in Minas Geraes, Brazil.*

These deposits of manganite and pyrolusite occur as beds up to 2 m. thick, traceable for over 2 km. (1.2 miles) along the strike. The beds occur intercalated in crystalline schists in the region, between the railway stations of Queluz and Miguel Burnier of the Brazilian Central railway.

According to Lisboa[1] the steeply upraised strata at Miguel Burnier show the following succession:

1. Mica schist.
2. White limestone with 1.5% manganese content (over 10 meters).
3. Impure earthy iron and manganese ore (24 meters).
4. Pure manganese ore, mostly hard (over 3 meters).
5. Itabirite (quart-schist rich in specular hematite).
6. Gray limestone with 1.5% manganese, 11% iron, 13.8% SiO_2.
7. Overlying mica schists.

The production reached 100,000 tons in 1900. The ores contain between 45 and 55% of manganese, and very little silica (up to 1.3%) and phosphorus (up to 0.07%). They are shipped from Rio de Janeiro to North America.

Similar deposits are exploited, according to J. C. Branner,[2] in the Pedras Pretas mine, 26 kilometers west of Nazareth in the State of Bahia.

B. Manganese Ores in Normal Sediments.

(a) *Manganese Ore Deposits in the Carboniferous.*

The ores obtained from the Kaiser Franz mine near Elbingerode, in the Harz, occur, according to W. Holzberger and C. Zerrenner,[3] as pocket-shaped intercalations a meter or so thick in the siliceous shales of the Culm.[4] The ore consists of psilomelane in dense and botryoidal masses, some pyrolusite and coatings of wad, with rhodonite, rhodochrosite and quartz present as accessories. The ore formerly worked contained on an average 60 to 63% of manganese peroxide, sometimes rising to 67%. Zerrenner considers these maganese ores as later material separated out of the siliceous shales, a theory which needs further investigation The bed-like deposits of rhodonite and manganspar near Lautenthal in the Harz, mentioned by Klockmann,[5] are found also in the siliceous shales of the Culm formation.

The manganese ore deposits of Alosno, north of Huelva, in Spain, which contain pyrolusite and psilomelane, are also said to belong to the lower Carboniferous (Culm).

Beds of psilomelane, pyrolusite and brown hematite, as well as those of arsenious black oxide of copper and malachite, are found in the horizontal

[1] R. Ribeiro Lisboa: *Jornal do Commercio*, June, 1898, and March, 1899. Review *Zeit. f. Prak. Geol.*, 1899, p. 256. H. K. Scott: 'Manganese ores of Brazil,' *Jour.* Iron and Steel Inst., London, 1900, No. 1.

[2] *Trans.* Am. Inst., Min. Eng., 1900 (Meeting September, 1899).

[3] W. Holzberger: 'Neues Vorkommen von Manganerzen bei Eibingerode am Harze,' *B. u. H. Z.*, 1859, p. 383. C. Zerrenner: 'Die Manganerz-Bergbaue in Deutschland, Frankreich und Spanien.' Freiberg, 1861, p. 103.

[4] The Culm is the basal formation of the Carboniferous of Eastern Europe.

[5] *B. u. H. d. Oberharzes*, p. 65.

upper Carboniferous (lower Nubian) sandstones of Wadi Nasb and Wadi Chalig of Mount Sinai.[1]

(b) *Mesozoic Manganese Deposits of Chile.*

The extensive manganese deposits in the districts of Coquimbo and Carrizal, in Chile, worked by the Chilean Manganese Mining Company, have received but little study as yet. According to H. Louis[2] they occur interbedded with Jurassic and Cretaceous sandstones, clay slates, limestones and gypsum that rest on eruptive rocks. The ores consist of manganese oxides, peroxides and silicates in a gangue of silica, calc and heavy spar, the ores averaging about 50% manganese and having very little phosphorus. Chile produces some 30,000 tons of manganese ore annually.

(c) *The Eocene Oolitic Manganese Ores of Transcaucasia.*

The principal manganese deposit of Transcaucasia lies near Tschiatura on the Kwirila river in the province of Kutais, 42 kilometers from Kwirila railway station on the Tiflis-Poti line. The ores form a nearly horizontal bed in the Eocene, underlain by limestones and marls of the Turonian, which, in their turn, are underlain by granite below Tschinopoli. The Eocene series begins with a red or greenish sand 0.4 to 4 meters thick, containing teeth of *Lamma elegans*. Above this follows the manganese ore bed, averaging 2 meters and reaching 5 meters thick. The bed is composed of 5 to 12 layers of hard oolitic pyrolusite, with a cement of pulverulent ore. It outcrops underneath the bluffs of the low plateaus into which the Tertiary has been dissected by the Kwirila river and its tributaries. The overlying strata are sandstones and limestones of later Tertiary epochs. The ore bed can be traced 120 kilometers, so that the bed will last a long time.

The average amount of manganese in the ores, as determined by F. Drake, is 40 to 45%, while within certain areas it rises to 50%. When dressed for shipment, the ore averages 51 to 52%, reaching as much as 61%. The ore averages 0.16% of phosphorus and not over 8% of silica.

According to the same authority, a complete analysis of concentrates exported from Tschiatura gave:

MnO_2	86.25%	Na_2O+K_2O	0.22%
Mn_3O_4	0.47 "	SiO_2	3.85 "
Fe_2O_3	0.61 "	CO_2	0.63 "
Cu O	0.01 "	S	0.23 "
Ni O	0.30 "	P_2O_5 (P=0.14)	0.32 "
Al_2O_3	1.74 "	H_2O	1.85 "
Ca O	1.73 "		
Mg O	0.20 "	Total	99.95%
Ba O	1.54 "	Mn	54.90 "

[1] M. Blankenhorn: 'Neues zur Geol. u. Paleon. Aegypten,' *Zeit. f. Prak. Geol.*, 1899, p. 392.

[2] 'Ore Deposits,' 1896, p. 878.

The brittle nature of the ore is a serious detriment in shipping.

The deposit was discovered in 1848 by the geologist Abich, and has been worked since 1879. In 1897 it produced 231,868 tons. The total production has already reached one and one-half million tons. The deposits of Samtredie and Novo-Senaki are similar.

European Russia, also, contains manganese ore deposits in the Eocene formation, at Nicopolis on the lower Dnieper. The manganese ore bed is 0.5 to 3 meters thick, and where worked it contains as high as 50% of manganese. The production in 1894 was about 58,000 tons.[1]

(d) *Recently Formed Deposits of Manganese Ore.*

The discovery that manganese-iron concretions of irregular flat forms are of frequent occurrence on the sea bottom at depths of 1,800 to 3,000 meters is of much genetic importance. In the region of the Gulf Stream the Albatross party found the sea bottom covered with them. Among them were pieces 2 to 15 centimeters thick and 10 kilograms in weight, the lower side of which often consists of tough, blue clay.

In a finely divided condition manganic hydrates in combination with ferric hydrates are, according to J. Walther[2], among the most widely distributed substances in marine sediments; all the rocks, shells, calcareous algæ and limestone fragments covering the sea bottom at Millport, Scotland, at a depth of 90 meters, show thin, black coatings of manganese compounds. The Challenger observed similar manganese coatings on pteropod and globigerina shells obtained from depths of 2,560 to 2,743 meters, and the dredgings corroborate previous observations showing the great distribution of the manganese concretions previously noted in the deep sea deposits of the Indian and Pacific oceans and in the vicinity of volcanic islands in the Atlantic Ocean[3].

[1] A. Macco: 'Reisebericht,' *Zeit. f. Prak. Geol.*, 1898, p. 203. F. Drake: 'The Manganese Ore Industry of the Caucasus,' *Trans.* Am. Inst. Min. Eng., Vol. XXVIII, 1899, pp. 191-208.

[2] 'Einleitung in die Geologie,' Jena, 1893-4, p. 700.

[3] Gümbel: 'Ueber die Manganknollen in Stillen Ocean.' *Sitz.* der K. Ak., Munich, 1878. Murray-Irvine: 'On the Manganese Oxides and Nodules in Marine Deposits,' *Trans.* Roy. Soc., Edinburgh, 1894, Vol. XXXVIII.

SECTION III.

EPIGENETIC DEPOSITS.

I. MINERAL VEINS.

A. General Description of Mineral Veins.

(a) Definition of the Term 'Mineral Vein.'

The material filling a fissure in the earth's crust is called a vein; if the material is igneous the vein is called a dike, if not, it is a true vein; if the material contains minerals of economic importance it is a *mineral vein*. More briefly, veins are fissure fillings; mineral veins are those containing ores. Their general form resembles that of ore-beds, since they are more or less irregular sheets wedging out in two directions, and showing great variations in thickness and great departures from rectilinear strike and dip. The enclosing rock is called *country* or *country rock* and the rock walls of the fissure are *vein walls*. The outer surface of these slab-shaped formations are often called *selvages*, but this term is only appropriate for the layer or sheet of clayey material, often soft and unctuous, which frequently lies between the body of the vein and the country rock. It is also known as *gouge* or fluccan.

As veins exhibit a great diversity in character, the definition of the term given above is not sufficient and needs amplification. According to Lindgren[1] a *fissure vein* is a mineral mass tabular in form as a whole, though often irregular in detail, filling or accompanying a fracture or set of fractures in the enclosing rock. This mineral mass has been formed later than both the country rock and the fracture, either through the filling of open spaces along the fracture or through chemical alteration of the adjoining rock. Many veins are not single fissure fillings, but zones of rock with numerous parallel, very narrow fissure fillings or stringers. Such lines of stringers practically form a *lode*, being, strictly speaking, composed of very small veins. According to Emmons,[2] "the term *vein* should be confined as far as possible to a single mineralized fissure, or the orebody formed along a single fissure, while the term *lode* is applied to an assemblage of ore-bearing

[1] W. Lindgren: 'Metasomatic Processes in Fissure-Veins'; 'Genesis of Ore Deposits,' 1902, p. 500.

[2] Text of Folio 39, U. S. Geol. Survey, 1899.

fissures so closely spaced that the ore that has been formed along and between them may in places be considered to form a single orebody. The principal fissures making up a lode are nearly parallel, but there are also smaller cross fissures connecting them, through which the intermediate country (granite) becomes impregnated with ore until it may constitute vein material. A lode may be only ten feet wide, or it may be a hundred or more; and within it are included zones of more or less altered country rock, sometimes carrying enough values to pay for mining; in others too barren to pay, when they are generally called *horses*. When there is an assemblage of veins too widely spaced to be included in a single lode, and

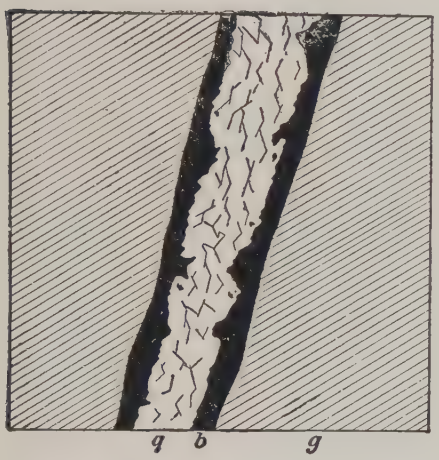


Fig. 53.—Simple vein (Krieg and Frieden Stehender of the Himmelfahrt, near Freiberg).
q, quartz; b, zinc-blende; g, gray gneiss.

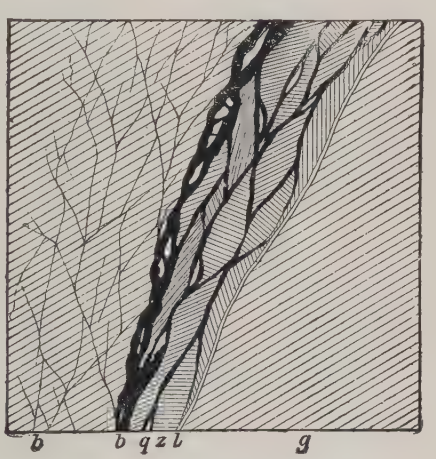


Fig. 54.—Compound vein.
b, lead glance; q, quartz; z, blocks of decomposed gneiss; l, clay selvage; g, gray gneiss.

yet to a certain extent coördinated into one system, they may be designated as a *vein system.*" The various stringers of such lodes may, indeed, have a transverse course. Parts of the country rock, either in great blocks or little bits, by means of such transverse and parallel stringers, may be entirely detached from connection with the country rock. B. von Cotta[1] has given the name *compound veins* to such lodes. They consist essentially of country rock traversed by ore stringers, thus differing from the simple fissure veins which, according to the general definition, are formed by the filling of a single fissure. This distinction was accepted by A. von Groddeck and is now much used. Compound veins or lodes often lack a sharp wall, at least

[1] 'Ueber den. sog. Gangthonschiefer von Clausthal,' *B. u. H. Z.*, 1864, p. 393.

on one side, and it is then left to the judgment of the observer to locate the boundary between the lode and the country rock.

The two figures, 53 and 54, represent these two types of lodes.

A part of a lode or compound vein is shown in Fig. 55, reproduced from a photograph.[1]

A good example of a so-called lode not embraced in any of the above definitions, but, on the contrary, representing a great, often very thick, zone of veins and lodes, is the famous mother-lode in California, containing numer-

Fig. 55.—Part of a lode or compound vein (of the Traugott Spat of the Gesegnete Bergmann's Hoffnung Mine, near Obergruna) showing gray gneiss traversed by narrow stringers of galena and some quartz.

ous gold quartz veins. Which one of the numerous parallel fissures of this zone are to be regarded as its bounding surfaces is a matter of arbitrary judgment and is of economic rather than of geologic interest.

Compound veins are common at Freiberg, Clausthal in the Harz and at Kremnitz in Hungary.

The term 'filling' may sometimes be misused in this connection. Certain veins, especially gold veins, are nothing less than zones of rock, traversed by innumerable practically barren fissures, from which they have been impregnated with gold-bearing pyrites or other ores to a workable

[1] Rickard: *Trans.* Am. Inst. Min. Eng., Vol. XXVI, p. 216.

degree. Such zones of disintegrated and impregnated rocks, called lodes by miners, usually coincide with lines of displacement. Finally, the definition of a filled fissure is unsuitable when the barren fissure, almost devoid of minerals, has been a conduit for solutions penetrating a zone of country rock on both sides and entirely replacing the rock by new-formed ores and other minerals, as seen in many galena deposits in limestone. The author (R. B.) does not entirely agree with S. F. Emmons,[1] who attributes an important rôle in the formation of many veins to metasomatic processes, as such processes are regarded by him as always subordinate phenomena in vein formation.

(b) Dimensional Relations of Mineral Veins.

"The width of the filled fissure, measured at right angles from wall to wall, is called the *thickness*. The rock in which the fissure has been opened is called the *country rock*. If the vein is not vertical the rock above is called the *hanging-wall* rock and that below the *footwall* rock. The horizontal direction of the vein is called the *strike*, that which comes nearest to the vertical is called its *dip*. If the body of the vein has undulations these may, by several observations, be plotted and reduced to a plane corresponding to the average attitude of the vein, on which the strike and dip is called the average or principal strike and the principal dip of the lode." (Von Cotta.)

The strike of a lode was usually determined in European mines by means of a miner's compass divided into twice twelve hours. The dip is ordinarily on a graduated circle connected with the compass. This form of compass is, however, not used outside of Europe, and even there is being more and more displaced, even among miners, by one with a graduation into twice 180°, and in most scientific monographs we find the strike of veins given in degrees, as has long been done in general geology.

The old division of veins into different categories, according to their strike and dip, long in use in the Erzgebirge of the Harz and other German mountains, is still used in Europe. The diagram (Fig. 56, page 116) gives the designations of this kind based on the strike.

According to this scheme, 'low' strike veins are those situated at the beginning of a division; 'high' strike veins are those situated near the end of it. A morgengang striking 4 hours is thus a 'low,' while one striking 5 hours is a 'high' lode. As to the veins striking almost centrally, 3, 6, 9 and 12 hours, they are said to strike in the alternating hours (Wechselstunden).

It is to be noted that in the German mines, in giving a name to a newly discovered vein, its insertion in one of the above named divisions was made

[1] 'Structural Relations of Ore Deposits.' *Trans.* Am. Inst. Min. Eng., February, 1888.

according to the observed magnetic strike, not the true strike, that is to say, without regard to the declination of the magnetic needle at the time. Furthermore, on the plats the name once given was retained, although greater development work might show that the portion of the vein first worked had a somewhat different strike from that of the vein as a whole. Thus it may happen that a vein mentioned on official plats and in diagrams as high-strike Spatgang really belongs to the group of Flache Gänge. Such contradictions have also arisen from the fact that when, at a much later time, a survey of the mine is made, the declination may have changed materially from that

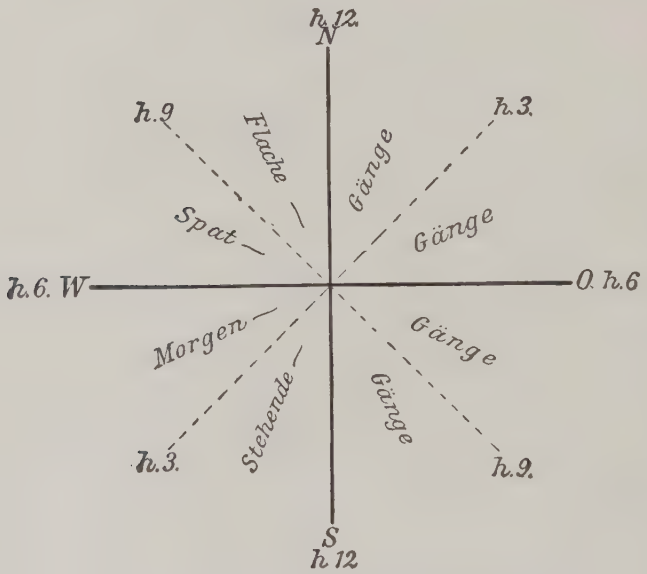


Fig. 56.—Division of veins according to their strike.

officially entered on older maps, and thus the observed strike may no longer agree with the older observations. Hence it is now the custom to plot the lodes with reduced strike, that is to say, referred to the true meridian.

In the Austrian mines the terminology is somewhat different. A compass divided into 24 hours is there generally used, and lodes striking between 21 and 3, or 9 and 15 hours, are called midnight lodes; those between 3 and 9, or 15 and 21, are called morning lodes.

The divisions according to the difference in dip are shown in the diagram (Fig. 57, page 117):

Most of the veins belong to groups between 90 and 75° or 75 and 45°; the other two divisions occur much more rarely. German terms rechtsin-

nig (right-wise) and windersinnig (contrary-wise) are not used in America and only have a local significance. In the Freiberg area, for example, most of the lodes dip west, and hence those members of the network of lodes that by way of exception dip east are said to dip contrary-wise. In another area the reverse may occur.

If a lode suddenly changes its dip it is said to 'get out of the hour'; to return to the old direction a short distance farther on it is said to 'strike or throw a hook.' The vein 'straightens up' if a prevailing low dip suddenly changes to a high dip; it 'flattens out' if the reverse takes place.

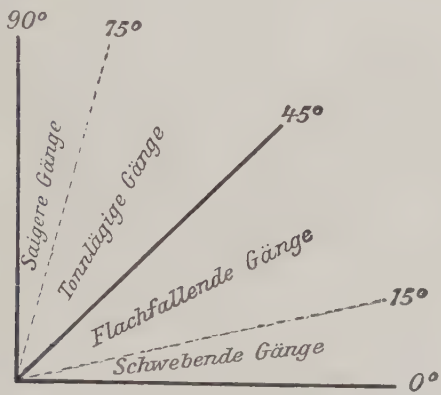


Fig. 57.—Division of veins according to their dip.

The thickness often shows great and frequent changes. It may be reduced to nothing, when the lode is said to pinch out (at "a," Fig. 58); to 'open up' perhaps a short distance farther on (at "b," Fig. 58).

In the great majority of veins the thickness varies between 0.5 to 1 meter. In the Freiberg area the greatest thickness shown by the barytic lead veins is 6 meters, while the others ordinarily vary between 0.15 to 0.5 meters. In exceptional cases lodes may be 50 meters and more thick, as, for example, the famous Comstock lode in Nevada and Veta Madre of Guanajuato,[1] Mexico. In such cases we are always dealing with combined lodes, made up of closely spaced parallel lodes, or broad zones of impregnated rock.

Veins of slight thickness are called stringers, veinlets, etc.

A vein showing frequent pinching out and widening up, repeated at short intervals, is called a lenticular vein (Playfair) (Fig. 59). When the lenses are approximately perpendicular, it may be defined as a series of pyrite

[1] Carl Henrich: 'Mines of Guanajuato, Mexico,' *Mining Magazine*, 1904, Vol. X, pp. 63-75, 101-108.

stocks. Such lenticular lodes, according to K. Schmeisser, are quite frequent, for example, in the region of Coolgardie, in western Australia, in the auriferous quartz lodes, especially the Edjudina lode group.

By 'leaves' the Austrian miner means 'fissures,' sometimes no thicker than a sheet of paper, which though barren themselves are sometimes accom-

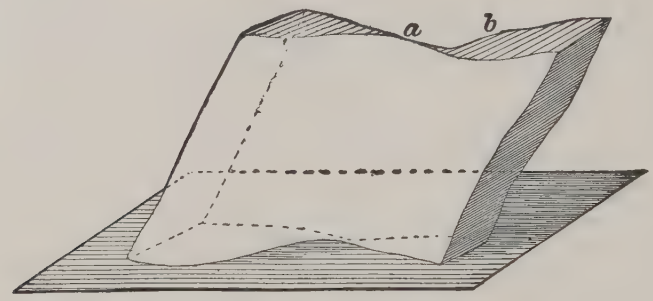


Fig. 58.—A lode which pinches out (a) and comes in or 'opens up' (b). (A. von Groddeck.)

panied by a zone of country rock impregnated with ore. At the Rathausberg, near Gastein, a whole system of such leaves exists in the gneiss or mica schist, between which the country rock proves to be impregnated with native gold and auriferous sulphides. The name leaves is also given to the fissures connected with the ores in the dolomite of Raibl.

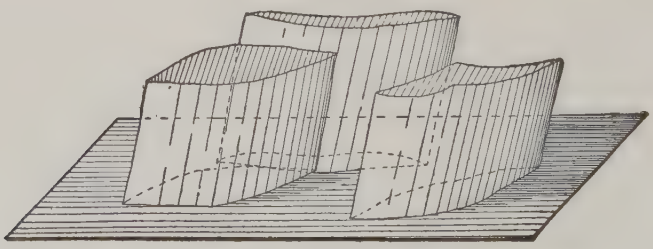


Fig. 59.—Lenticular lodes.

Somewhat similar fissures, called Zwitterbander, *i. e.*, narrow fissures, are often no thicker than a knife-blade, filled with quartz, topaz, lepidolite, fluorspar and a little tin ore, from which the country rock, granite or schist has been 'impregnated,' as it is expressed by the Saxon miners, with tinstone and its accompaniments, on both sides to a distance of 1 to 10 centimeters from the fissure.

'Verticals' are similar to the 'leaves' just noted. The term is used in the Black Hills of Dakota for barren fissures that have been channels for mineralizing solutions forming ores in favorable strata.

(c) The Termination of a Vein.

The vein 'wedges out' if its sides gradually converge and finally join (Fig. 60). Often, however, a joint plane, at least, continues on through the rock, often showing as a mere film of clay. In case the vein splits up into narrow stringers it is said to 'fray out' (Fig. 61). As an example one may mention the branching sub-division of the tin veins of Sau-

Fig. 60.—A vein wedging out below.

Fig. 61.—A vein dividing below.

berg, near Ehrenfriedersdorf in the Erzgebirge, a short distance before they reach the surface. Very often veins subdivide when they pass from a firm into a more brittle rock. Thus the Freiberg veins very frequently divide on passing out of the gneiss, whose toughness favors the development of a uniform single vein into the quartz porphyry dikes which pass through the gneiss. Figure 62 shows the behavior of the Gottlob Morgengang, at the David Richt shaft near Freiberg, where it passes through such a porphyry dike. The vein retains its full thickness up to the porphyry, but on entering it becomes scattered into numerous more or less parallel stringers. Immediately after leaving the quartz porphyry it resumes its previous condition. It is to be noted, however, that this division into stringers does not take place in all cases where the porphyries in the Freiberg area are tra-

versed by ore lodes. If the vein strikes the porphyry at a blunt angle it may pass through it smoothly and without material impoverishment.

A similarly instructive example described by T. A. Rickard[1] occurs in the silver veins of the Enterprise mine of Colorado. These divide and grow barren in the limestone, but cut cleanly and with a fine body of rich ore through the sandstones that alternate with the limestone. Similarly, in the tourmaline bearing quartzose elvans (quartz porphyry) of Cornwall,

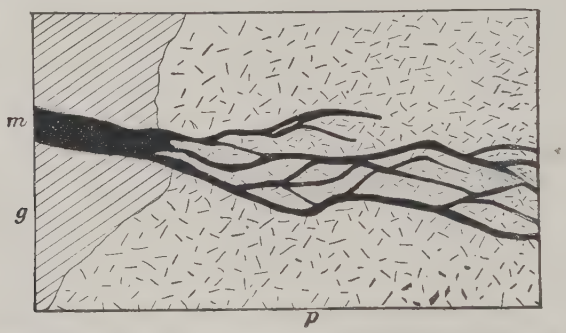


Fig. 62.—Scattering of the Gottlob Morgengang in the David Richt shaft near Freiberg. g, gray gneiss; p, quartz porphyry; m, ore lode.

the veins, according to W. J. Henwood[2], ordinarily divide into countless stringers, which re-unite when the vein passes into a softer rock richer in feldspar. Similar conditions are observed in the veins of the Spitzenberg near Silberberg in Silesia, where the vein passes from the gneiss into the overlying graywackes.

A very gradual fading and 'dying out' of veins does not occur in true vein fissures, but only in veinlike ore-bearing streaks in eruptive rocks, as in the case of ilmenite streaks in the norite of Ekersund in Norway (see p. 34).

Conversely several individual vein-stringers may converge and unite or 'gather' into a larger vein. This will be more fully discussed in the section or vein intersections (p. 132).

A *cross stringer* or *diagonal* is one which connects, at an acute or obtuse angle, two parallel or diverging veins (Fig. 63), as, for example, a stringer between the Burgstadter main vein and the Kranicher vein on the upper Harz. A crescentic stringer, on the contrary, runs out from the main vein at an acute angle, to return to it again at an acute angle some distance away (Fig. 64). The English-speaking miner calls the block between two such branch lodes a *horse,* and the outer vein about it, on a corresponding

[1] *Trans.* Am. Inst. Min. Eng., 1897, Vol. XXVI, p. 197.

[2] *Trans.* Roy. Geol. Soc., Cornwall, 1843, pp. 219-225.

analogy, a *rider*. Typical branching lodes are found, for example, at the Bockwieser main lode on the upper Harz. Side stringers or companions (Fig. 64) are small stringers parallel to the main lode, but not converging toward it, as, for instance, in the Neu Hoffnung Flachen on Himmelfahrt near Freiberg. *Feeders* and *droppers* are small veins or stringers falling into the hanging-wall (*i. e.*, intersecting vertically), or running out and down from the footwall of a vein.

A total cutting off of a lode can be caused only by younger veins or faults or by eruptive masses or dikes.

(d) Length and Vertical Extent of Veins.

In speaking of veins, we distinguish between the *length* along the strike, that is, the longitudinal extension of the vein, and its *depth* or downward extension on the dip. Veins vary greatly in both length and depth. In districts where there are several varieties of mineral veins with different contents, the varieties sometimes differ also in longitudinal extension. Thus in the Freiberg area the barytic lead veins show the greatest length; the length of the Halsbrücker Spates with its associated stringers being 8.4 kilometers (5.0 miles). One of the pyrite-blende lead veins, the Kirschbaum Stehende, and its southward continuation, the Hohn Birke Stehende, shows

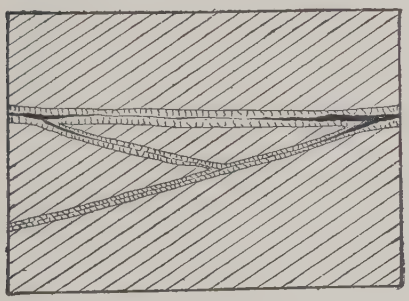


Fig. 63.—Two veins converging eastward, and connected by a diagonal stringer.

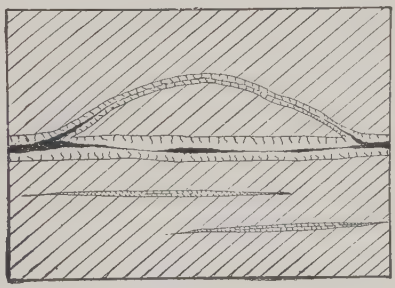


Fig. 64.—A mineral vein with an arched stringer and two side stringers.

a length of 7 kilometers (4.2 miles). The veins of the rich lead formation were in most cases traced only 1 kilometer (0.6 mile), but three veins, Johnannes St., Neuglückstern and the Neue Hohe Birke St., near Bescheert Glück, have a length of over 2 km. (1.2 miles). Finally the longest rich-silver-quartz-lodes were only traced 1.5 kilometers. Much longer veins occur in the Harz mountains. Thus, the Rosenhöfer, Rosenbüscher and Schulthaler lodes form the filling of a compound lode fissure 16.3 km. (9.84

miles) long (von Groddeck), and the Gegenthal-Wittenberger series attains a length of 18 km. (10.8 miles). The mineralized zone or gold belt of California, known as the Mother lode, does not conform to the definition given of either a vein or lode, being rather a system of veins. Its length is estimated at about 67 miles (112 kilometers).

The question "How far do veins extend downward?" is a most important one. Most veins continue downward below the lowest mine workings of the region, or, as the miner says, "to the eternal depths." Very often the older reports on mineral veins stated that this or that lode came to an end at a certain depth. More often, however, the vein ceased to pay and was abandoned. In many cases various difficulties of mining, or finance, prevented the exploration work necessary for its development, and in many instances subsequent workings have led to the rediscovery of apparently lost lodes at considerably greater depth. Thus, in the earlier descriptions of the Bescheert-Glück lodes between Freiberg and Brand they are said to be 'sod runners' confined to the upper strata. This, however, has been disproved by the later workings at that locality. Modern technical appliances have sometimes enabled lodes to be followed down to very great depths without disclosing any notable change in the character of the fissure fillings. Thus, the development of the Adalbert lode at Pribram has reached a depth of 3,640 feet (1,110 meters), or 564 m. (1,850 ft.) below sea-level. The lodes of the upper Harz have been followed to a depth of over 850 m. (2,788 ft.). In Freiberg, the Wernerian doctrine long prevailed that mineral veins are surface phenomena of the earth's crust. It was von Beust who exposed the falsity of this theory. He urgently recommended deep mining on a large scale, so that the Tiefe Rothschönbreger shaft, planned as early as 1838 by von Herder, was put down and the veins worked to a depth of over 650 m. (2,132 ft.). Veins have been followed to great depths in many other districts, for example, the gold veins of the Bendigo gold field in Victoria are mined to a depth of 1,219 m. (4,000 ft.). In general the empiric rule is that veins with a great horizontal extent continue to great depth, while those which extend for only a short distance along the surface do not go far downward.

It must be remembered, of course, that the greatest depths reached in mining operations are exceedingly small when compared with the radius of the earth, and even with the latest mechanical improvements the depths to which mines may be worked will still be relatively small. There is, however, a theoretical interest in the question to what depth ore lodes may possibly extend.

A discussion of his observations on rock metamorphism and of the known conditions of the geothermic gradation, as gathered from thermal

springs, led A. Heim[1] to assume that water-filled open fissures may extend to a depth of 3,000 to 4,000 meters without being instantly closed by the tremendous side pressure in the earth's crust. Recently C. R. Van Hise[2] has been engaged on a theoretical investigation as to what depth fissure formation is possible. In his opinion the zone of the plastic condition of the rocks (zone of flowage) begins at 10,000 to 12,000 m. (32,810 to 39,372 ft.), because from there downward the weight of the superincumbent mass is too great to allow even the hardest rocks to retain their form. The fissure formation from there downward is replaced by flowage due to a displacement of the small particles, which is not infrequently combined with solution and recrystallization of mineral substance (granulation and recrystallization).

According to the same author it must not be supposed that at a particular depth, even above that zone, the water in a fissure will be transformed into steam. True, if we assume a geothermic gradation of 30 m. (98 ft.) the critical temperature of water, 364° C., would prevail at a depth of not more than 10,920 m. (35,810 ft.), but this is true only if we disregard the pressure of the column of water. In reality this hydrostatic pressure is at any given depth in a fissure abundantly sufficient to retain the water in liquid form.

Many mineral veins terminate upward and do not show on the surface; that is to say, do not outcrop. This is illustrated by numerous well-described examples, although it must be remembered that errors in this respect are readily committed because the uppermost part of the ore lode may have been disfigured beyond recognition by atmospheric influences. Such a limitation in upward extension is found in the so-called cobalt ridges (Rücken) of Riechelsdorf in Hesse (von Leonhard). In the Freiberg area most of the lodes of the Himmelsfürst mine show no outcrop, not even that of the Silberfund Stehende, which in depth attains large dimensions. At the Segen Gottes shaft and the Moritz shaft, according to E. W. Neubert,[3] the projection of this lode was several times passed through without the vein being encountered. Similar reports are made in regard to the Neu Glück Stehende of the Alte Hoffnung Gottes mine. Finally a very remarkable condition is reported by T. A. Rickard[4] at the Enterprise mine, Colorado. The numerous silver-gold veins cut through gently inclined beds of Carboniferous rocks, but could only be followed upward from the floor of the

[1] 'Mechanismus,' etc., Vol. II, 1878, p. 107.

[2] *Trans.* Am. Inst. Min. Eng., February, 1900, pp. 7, 9, 11. Reprinted with papers by Posepny, Emmons, Lindgren, Weed, Vogt, Kemp, Rickard, etc., in 'Genesis of Ore Deposits,' 1902.

[3] *Freiberger Jahrbuch*, 1881, p. 51.

[4] 'The Enterprise Mine,' *Trans.* Am. Inst. Min. Eng., Vol. XXVI, 1896, p. 975.

Group tunnel to the horizon formed by a bed of shale (Fig. 65). Before reaching this horizon the veins became much poorer and were no longer workable; but along the contact or bedding plane there are flat and very rich orebodies whose composition is similar to that of the lodes. According to Rickard's explanation the somewhat plastic shales, offering resistance to the opening of fissures, were not cut by the veins, and the solutions rising through the open fissures were dammed back by the shales and spread out along this horizon. The carbonaceous material of this shale led to the precipitation of the metallic compounds contained by the stagnant solutions, thus giving rise to bedded ore masses.

A vein may also fray out upward before reaching the surface, only its smaller branches outcropping, as was the case in the famous silver-tin veins of the quartz-trachyte Cerro de Potosi in Bolivia (A. W. Stelzner). At Nag-

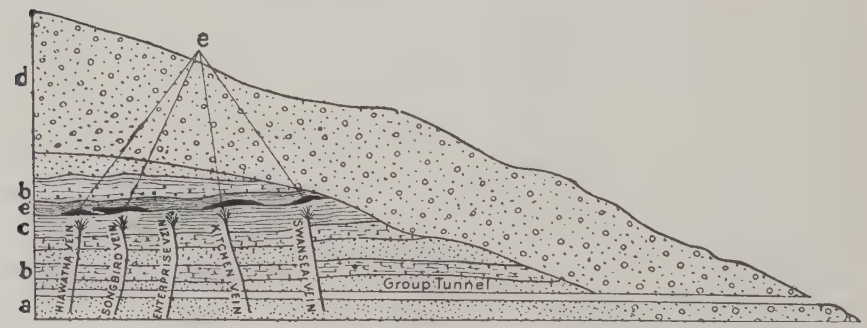


Fig. 65.—The termination of mineral veins at the top of the Enterprise mine. (Rickard.)

a, sandstone; b, limestone; c, shale; d, younger overlying rock; e, ore-beds in the so-called contact.

yag, too, many fissures fail to reach the surface (J. Grimm). The outcrop of a vein is not always distinctly recognizable at the earth's surface. If the predominant gangue is a hard material, resisting weathering, a vein may project as a rocky crest or a low wall, as is so often the case with gold-quartz lodes, which for that reason are called *reefs* and *ledges*. On the contrary, a vein may be marked along the surface by a trench-like depression if the vein filling consists of carbonates and easily decomposed ores. (See also description of gossan formation below.)

The outcrop of a lode, like that of a bed, may be exposed or covered, that is to say, concealed by younger deposits. Pleistocene alluvium is particularly apt to form such mantles over lode outcrops, but igneous intrusions

may also do so, as is seen at El Oro, Mexico, where andesitic lavas conceal the outcrops.

(e) Structural Relations of Veins to Country Rock.

The most common type of vein is that which cuts across the stratification of the country rock and is, therefore, called a cross vein (Fig. 66). When the lodes have the same strike and dip as the country rock, they are commonly called *bedded veins* (Fig. 67). The type is very common among gold quartz veins, which usually show numerous lenticular swellings of the vein quartz.

It is often difficult to distinguish these bedded veins from true strata. The principal features by which doubtful cases of such veins can be recognized are, 1st, the occurrence of local cut-offs of the stratification; 2d, the presence of small transverse stringers; and, 3d, the presence in the district of genuine fissure lodes of similar or identical composition. The true vein

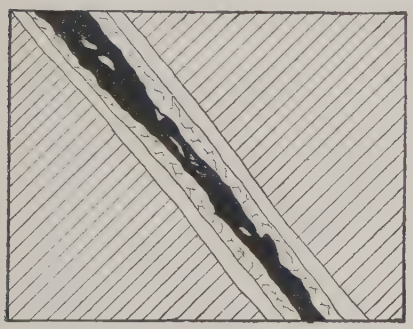


Fig. 66.—A cross vein.

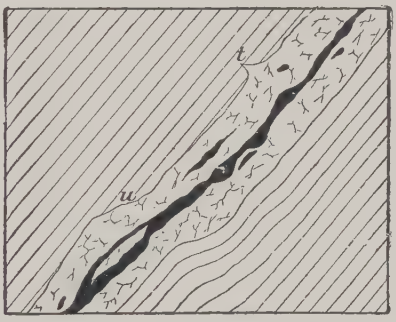


Fig. 67.—A bedded or stratum vein. At u, a local cut-off; at t, a small side stringer.

nature may also be proved by the presence of fragments of country rock in the midst of the vein filling.

A special form of bedded vein is known as a *saddle reef*. The best examples are those of the Bendigo goldfield of Victoria, which have been described by Dunn,[1] Rickard,[2] Pittmann, Samuels,[3] Schmeisser and Vogelsang.[4] As they are a new type they warrant a somewhat detailed description.

[1] Dunn: 'Report on the Bendigo Gold Fields,' Published by the Victoria Mines Department, Melbourne.

[2] Rickard, T. A.: 'The Bendigo Gold Field.' *Trans.* Amer. Inst. Min. Eng., Vol. XX, 1891, p. 499.

[3] Samuels: 'Origin of the Bendigo Saddle Reefs.' *Zeit. f. Prak. Geol.*, 1894, p. 95.

[4] K. Schmeisser and K. Vogelsang: 'Die Goldfelder Australiens.' Berlin, 1897, p. 64.

The Silurian shales and sandstones of Bendigo have been sharply folded into anticlines and synclines and the strata at the flexure points have slipped upon one another in such a way as to form cavities in the arches and troughs. (Fig. 68.)

The reefs are arch-like masses of quartz filling the cavities of anticlines and the bowl or trough-shaped synclines (inverted saddles). The quartz contains both free gold and finely distributed auriferous sulphides, and sometimes encloses angular fragments of country rock. These fragments, and the presence of short transverse stringers running from the quartz bed into the underlying layers, prove the deposits to be true veins (Fig. 69). Sev-

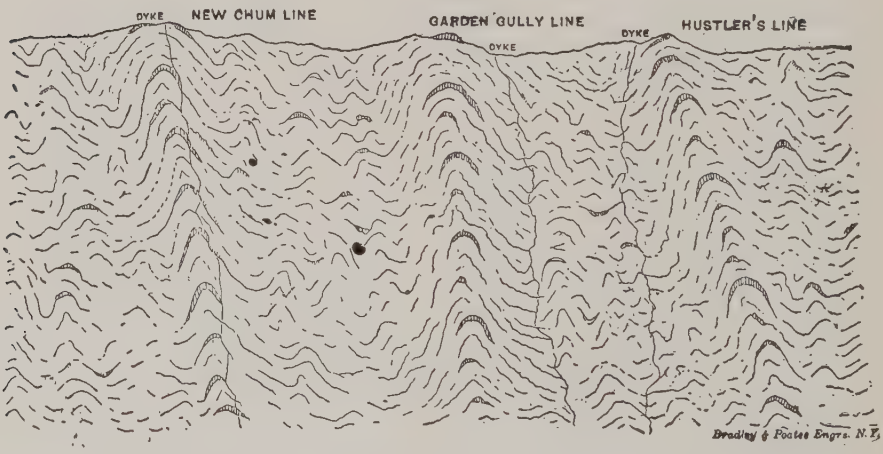


Fig. 68.—Ideal section through the Bendigo goldfield. (T. A. Rickard.)

eral groups of saddle-veins may follow one another at greater or less distances. They are often quite large, the anticline of the New Chum mine being exposed for a distance of 22 km. (14 miles) and to a depth of 975 m. (3,200 ft.) Besides these saddle reefs, ordinary quartz veins of similar mineralogic composition also occur in the district.

Similar anticlinal deposits have been described by E. R. Faribault from Nova Scotia (see under Stratified Gold Ore Deposits).

The famous deposit of Broken Hill in the Barrier range, New South Wales, is, according to E. F. Pittman and J. B. Jaquet,[1] regarded as a great anticlinal deposit, as indicated in the detailed description which is given later.

[1] J. B. Jaquet: 'Geology of the Brokenhill Lode, etc.' Sydney, 1894. R. Beck: 'Beiträge zur Kenntniss von Brokenhill.' *Zeit. f. Prak. Geol.*, 1899, p 65.

Quartz segregations, on a very small scale, often occur in clay slates, phyllites and mica schists, in which the foliations have been forced apart by folding. Sometimes these quartz lenticules contain gold.

Bedded veins are most frequent in platy or shaly or foliated rocks in which the bedding planes are marked by very distinct joints and are not apt to occur in heavy bedded, more brittle rocks.

Bedded veins are simulated when the beds along the walls of a quartz-

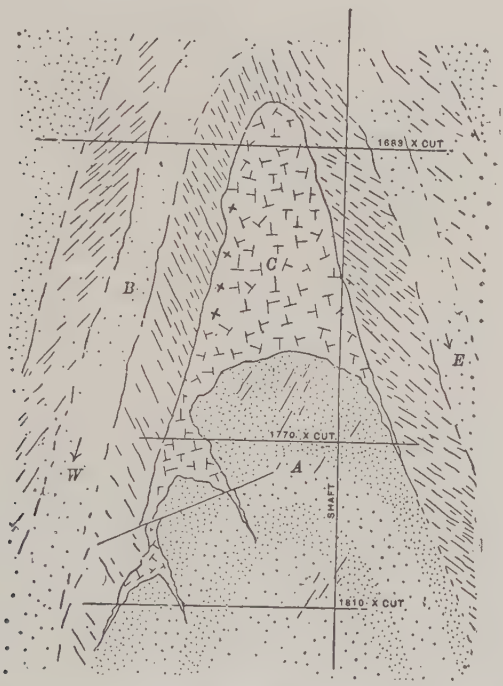


Fig. 69.—Section through the saddle reef of the New Chum Consolidated Mine, Bendigo, Victoria. (T. A. Rickard.)

A, sandstone; *B*, shaly sandstone, with quartz strings; *C*, lode quartz with gold and sulphides.

filled fault are bent so that the layers lying against the vein wall are parallel to it, as figured further on.

Gash veins are commonly understood to be those formed in joints and cross fissures in limestone, which have been widened by the solvent action of circulating water and filled by galena, zinc-blende and other ores. A characteristic feature of this variety of vein is the very short length and depth in strike and dip, and the association with certain calcareous beds,

and absence in intercalated slates. Figure 70, after Whitney, illustrates their mode of occurrence; the form is especially common in the Carboniferous limestones of southwestern Missouri. They might, perhaps, be fitly called solution deposits, due to leaching out along veinlets (Auslaugung trümer), that is, fissures enlarged by solution and filled with ore. They belong to the group of irregular cavity fillings, not to true veins.

The *pipe veins,* as certain tubes of ore have been called which traverse

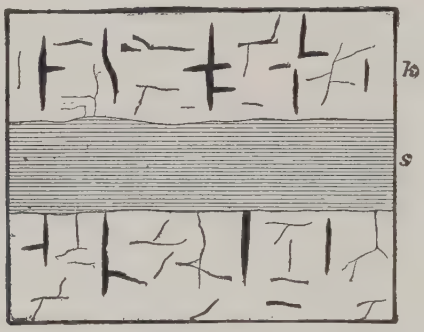


Fig. 70.—Gash veins, after Whitney.
k, limestone with stringers of lead glance; s, slate.

the stratification of limestone obliquely, are of similar class and origin; they present a strong contrast to the cavity fillings called *flats,* which are parallel to the bedding. A more extended application of this term seems to us inappropriate, an opinion already expressed by R. W. Raymond[1].

Columnar deposits are occasionally formed by the stretching and squeezing out of beds between more resistant strata. Thus the ore chimneys of Raposos in Brazil are not true veins, but masses of quartzite impregnated with auriferous pyrite and arsenopyrite.[2] *Chambered vein* is the name given by G. F. Becker to a type of deposit common in the quicksilver deposits of California. Fig. 71 shows the difference between an ordinary and a chambered vein. In this type the vein proper is connected with very irregular, large stock-like orebodies extending from the vein into an insoluble country rock. Their origin is supposed to be due to a condition of varying cohesion of the country rock, the weaker parts of which, when subjected to torsional forces, became broken and crushed. Chambered veins are, however, very different from cavities dissolved in limestones, which are connected with vein fissures in a similar manner.

[1] 'What is a pipe vein?' *Trans.* Am. Inst. Min. Eng., Vol. VI, 1879, p. 393.
[2] G. Berg: 'Goldlagerstätten von Raposos.' *Zeit. f. Prak. Geol.,* 1902, p. 81.

Contact veins occur at the boundary between sedimentary and igneous rocks. Underground water, circulating mainly along joints, and to some extent in pre-existing quartz veins, is checked when it encounters intrusive eruptive masses, because the igneous rocks are less permeable. The flowage thus checked may spread out laterally along the contact plane, because it is the path of least resistance, and in doing so the waters may deposit such substances as they held in solution. In other cases the cooling of eruptive rocks may have formed contraction fissures subsequently filled by ores.

A typical example of such a contact lode is seen in the Haile gold mine in South Carolina, described by H. Credner[1] and illustrated in Fig. 72.

According to J. H. L. Vogt[2] well developed contact lodes (with copper ore in quartz) accompany granite dikes which traverse quartzite slate at the Moberg mine in Thelemarken.

Fine examples occur in Idaho, in which quartz veins overlie or underlie dikes of porphyry or basic rocks.[3] In some cases faults form contact veins. A good example of this variety of contact vein is seen in the Johannes mine, near Schwarzenberg, described by Charpentier.[4] An ordinary hematite vein 2 to 17 meters thick has been opened to a depth of 200 meters. Near the outcrop the vein follows the contact plane between granite and mica schist, but in depth it passes into the granite. Its origin through general

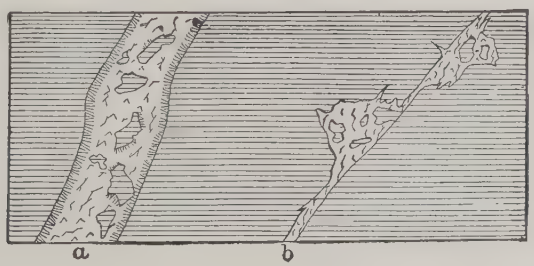


Fig. 71.—Ordinary vein (a); chambered vein (b). (G. F. Becker.)

orogenic causes is shown by its great length; it extends 7 kilometers northward (to Lauter) and passes through alternations of gneiss and mica schist.

The well-known contact lode of the old Haus Baden mine, near Badenweiler, is also a fault fissure. It traverses granite and the Bunter sandstone

[1] *Zeit. f. d. ges. Natur*, 1870, Vol. XXXV, p. 20.

[2] J. H. L. Vogt: 'Zur Classification der Erzvorkommen.' *Zeit. f. Prak. Geol.*, 1895, p. 149.

[3] W. Lindgren: 'The Mining Districts of the Idaho Basin.' Washington, 1898, p. 701.

[4] Charpentier: 'Mineralogische Geographie von Sachsen,' 1778, p. 248.

and contains quartz, barite, fluorspar, galena, copper pyrite and copper glance (G. Leonhard). At this place the Bunter sandstone, the normal stratified rock, is younger than the eruptive rock. The term *contact vein* should properly be restricted to only those which coincide with a real eruptive contact.

(f) Relations of Veins to Each Other.

Several veins with approximately identical strike are called parallel lodes, as, for example, the gold quartz lodes of the Sierra Nevada in California, which run parallel to the longitudinal axis of the range; and the fifteen lead veins of Svenningdal in Norway, which run at right angles to the strike of the strata.

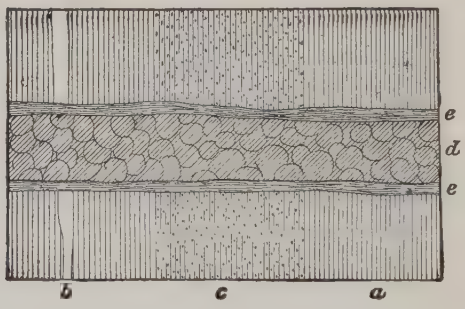


Fig. 72.—Contact veins of Haile gold mine, South Carolina. (H. Credner.)
a, quartz schist; b, quartz; c, quartz schist with auriferous pyrite; d, diorite vein; e, brown hematite contact lodes.

Radiating veins is a term applied to a cluster of veins diverging approximately from one point. The arrangement of the veins of the upper Harz might serve as an example. (See map sketch Fig. 156.) Typical radiating veins exist in the Cerro de Potosi, Bolivia, tin deposits. Systems of parallel lodes are called *series.*

The orientation of the vein series of Saxony has been studied in detail.[1] The special geologic maps of that kingdom show them as generalized by H. Müller. As may be seen by the map of the Freiberg veins, accompanying this work, two main directions may be distinguished in the strike of the Freiberg lodes: 1. A series with a few deviations between north-south and northeast. Though this series does not coincide exactly with the main northeast strike of the Erzgebirge, it is very close to it, and hence is called the Erzgebirge series. 2. A series striking between northwest and west-

[1] F. C. v. Beust: 'Gangkarte über den inneren Theil des Freiberger Bergrevieres nebst Erläuterungen.' Leipzig, 1842. Also 'Ueber die Erzgangzüge im sächsischen Erzgebirge in ihrer Beziehung zu den dasigen Porphyrzügen.' Freiberg, 1856.

northwest is called the Harz system, because it coincides with the main strike of the Harz. Upon close examination of the special map it appears that the several vein formations distinguished in Saxony (see later) favor one of these directions. The pyrite-blende-lead veins, which predominate at Freiberg itself, as well as the rich silver quartz veins developed at a distance from the town near Bräunsdorf and Gross-Voigtsberg, also have a course parallel to the Erzgebirge; the lead barite veins and many barren lodes run with the axis of the Harz mountains,while the galena and the spathic lead veins have numerous representations in both series, especially in the areas called Bescheert Glück and Himmelsfürst, near Brand.

The Harz (Hercynian) direction is also followed by a majority of the iron ore and cobalt lodes of the upper Erzgebirge, especially in the Schwarzenberg and Schneeberg areas. The formation of all these more or less parallel ranges is evidently connected with the main uplift and folding of the Erzgebirge, which occurred in Permian and late Carboniferous time. In fact, post-Cretaceous mountain-building forces have formed entirely different systems of fissures at other localities, as is so plainly seen in the directions of the two systems of barren fissures so numerous in the so-called Saxon-Switzerland fissures, which, as a whole, form two series similar in orientation to those already noted. The same rule holds true in many other mining areas; thus an exact plotting of the prevailing strike of the veins of a district may lead to important inferences as regards the general structure and *vice versa*. In the Freiberg area, which we have used as an illustration, local orogenic processes, as well as general ones, have evidently been active in forming the network of veins. It should be particularly noted that the gneisses of the Freiberg area form a dome whose summit is traversed by the veins.

When in a certain area the veins strike irregularly in all directions the network of lodes is called a *stockwork*.[1] Thus innumerable tin lodes occur in the granite at Altenberg in the Erzgebirge, and with the intervening country rock which is impregnated with ore, form what is called the "Altenberger Stockwerk." Similar stockworks also occur at several other localities in the Erzgebirge. In Cornwall a tangle of tin veins has penetrated the rock so generally, and at the same time has impregnated it with tin ore so abundantly, that large masses of rock have been mined out as ore, and vast chambers mined out at different levels. Mention may also be made of the Geyer stockwork, whose workings, like those of the Altenberger Zwitterstock, collapsed, forming a great basin.

[1] This German term, adopted in both French and English literature, applies to a mass of granitic rock traversed by a network of small veins, interlacing with one another and traversing the rock in all directions, but the ore also impregnates the interlacing rock. (Louis.)

Many vein aggregates resembling stockworks are also found in the gold ore district of Transylvania; for example, at Offenbanya, where trachyte breccia in the Kreisova stock is penetrated by innumerable gold- and silver-bearing veins.

(g) Structural Relations of Two Veins to Each Other.

Double Veins. When a fissure vein has been reopened and a new fissure formed, usually along one wall, but sometimes through the middle portion of the vein, and this fracture is filled by the deposition of material which may be unlike that of the primary vein, the result is a double vein, which may be composed of different layers or bands. Thus, for example, several of the veins at Himmelsfürst, near Brand, in the Erzgebirge, consist of a band of galena or brown spar ore, and a harder layer, which must be classed as a pyritic blendic lead vein. A similar condition is observed at the Christian Stehende at Himmelfahrt, near Freiberg. A specially instructive example of double lode is the famous Halsbrücker Spat near Freiberg. It consists of a soft band, composed chiefly of thin layers of barite, containing a slightly argentiferous galena, while a hard band consists of ferruginous quartz with highly argentiferous galena and rich silver ores. These two divisions of the vein diverge northwestward and are worked as separate veins—the soft stringer as the Drei Prinzen Spat, the hard as the Ludwig Spat (H. Müller).

If two approximately parallel veins are, as a whole, separate and only occasionally combine into a double lode, one lode (a) is said to drag against the other (b) (Fig. 73). If after their meeting they remain permanently connected, they are *combined* or are said to have joined.

If two veins cross, either in the strike or dip, the veins intersect. Intersections are further subdivided into:

1. Rectangular intersections (Fig. 74) when the strikes of the two lodes are at right angles.

2. Convergent intersections (Fig. 75) when the veins cross at an acute angle.

3. A dip intersection occurs (Fig. 76) when the veins are parallel in the strike, but intersect in dip.

As the lode cutting across another must necessarily always be the younger, the relations of two lodes to each other is used to determine their relative age.

For this purpose, it is, of course, necessary that the filling of the two veins shall be of different nature, or at any rate that one of them shall show distinct layers or crusts, in order that one may see whether the layers of the one pass through the mass of the other. Fig. 77 shows a simple vein crossing between an older stringer (a) with a younger barite stringer (b).

In very rare cases two intersecting fissures have been filled at the same time. If both veins show a banded structure or crustification, the layers of

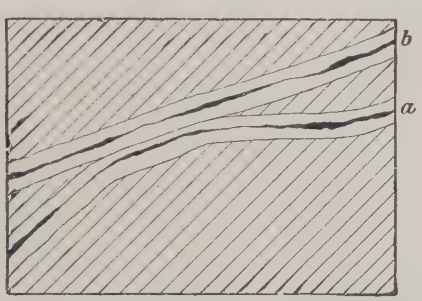


Fig. 73.—One vein (a) drags against another (b).

one vein pass uninterruptedly into those of the other. An excellent example is shown in Fig. 78 recorded by K. A. Külm.[1] It repre-

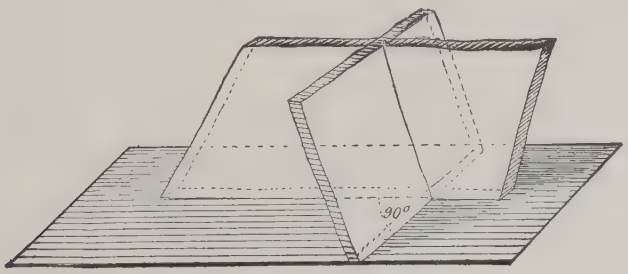


Fig. 74.—A rectangular intersection.

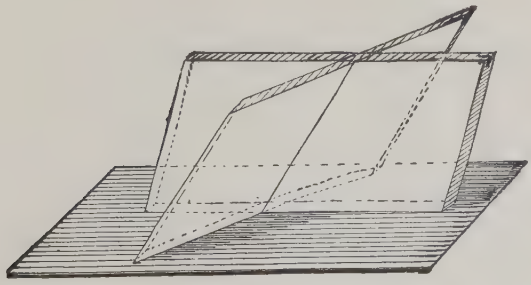


Fig. 75.—A convergent intersection.

sents a crossing of the Karl and the Ludwig veins in the now abandoned Habacht Fundgrube near Freiberg (Bescheert Glück). "The two lodes,

[1] 'Handbuch der Geognosie,' Freiberg, 1836, Vol. II, p. 604.

each of an average thickness of 10 to 15 cm. (4 to 6 in.), join in such a way that the outermost crust of quartz (q) and the second of rose spar (r) pass without interruption from the one into the other, while the third, a mix-

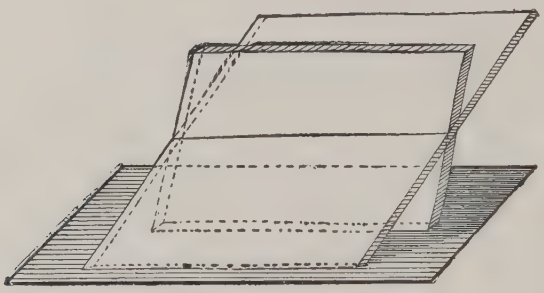


Fig. 76.—An intersection in dip.

ture of rose spar, argentiferous black zinc-blende and argentiferous galena (b), encloses within the space formed by the two lodes a druse-like cavity 18 to 23 cm. (7 to 9 in.) long." This druse is lined with quartz crystals.

Fig. 77. —Appearance of the Segen Gottes Stehenden vein of the Simon mine at Freiberg. (Weissenbach.)

A similar description is given by K. Dalmer[1] of the crossing of the flat dipping veins with the horizontal tin veins at Zinnwald in the Erzgebirge. In this case, too, there is no intersection, but a coalescence of the vein fillings as well as of the greisen zones on both sides.

[2] 'Erläut. z. S. Altenburg-Zinnwald,' p. 36.

A *deflection* of a vein occurs when one vein drags against another for some distance and then cuts through and along it (compare, on this point, Figs. 79 and 80).

It sometimes happens that the approaching vein breaks up into stringers, only a few of the stringers passing through the other lode and uniting on the other side again to form the lode with its former thickness. This breaking up may take place on one side only, while on the other the lode may at first appear nearly as a single, feeble stringer, as in the example (Fig. 81) from Andreasberg. In this case the deflection is produced not by an ore

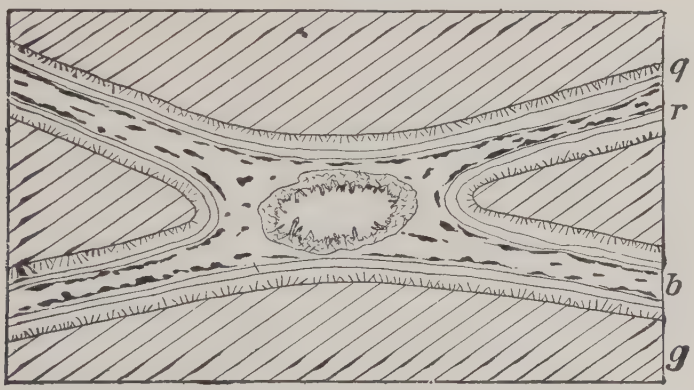


Fig. 78.—Vein crossing with simultaneous filling. (Kühn.)
g, gray gneiss; q, quartz; r, rose spar; b, rose spar with zinc-blende and galena. In the center a quartz druse.

vein, but by a fault (geschiebe) fissure filled with crushed country rock and traversed by many slip planes.

Sometimes a vein splits into stringers as it approaches another, and at that point stops, as shown in the example (Fig. 82) described by von Weissenbach.

The deflection of younger veins against older ones before the older vein is actually reached is due to numerous shear planes or joints approximately parallel to the older fissure and closely spaced, but which may be so fine that they are barely recognizable. The force producing the later vein would be relieved or entirely changed in direction along the shear planes, as well as by the older fissure, since the new fissure would follow the line of least resistance in the rock.

Fault fissures filled by attrition breccia and mashed country rock also cause vein deflections. Thus the so-called Ruscheln (rotten lodes) cause deflection of mineral veins even more frequently than other veins do. By

Ruscheln the Harz miner designates systems of parallel closely spaced, overthrust fault planes filled with completely crushed and ground up coun-

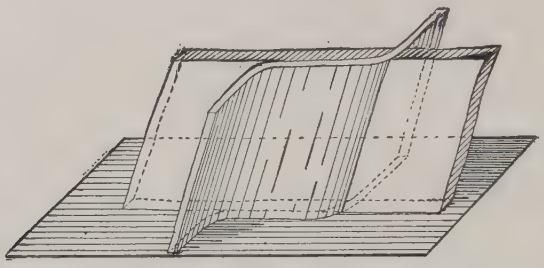


Fig. 79.—Deflection of a vein on passing through another. (Veins crossing without displacement).

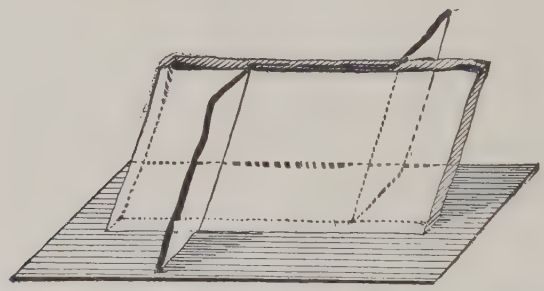


Fig. 80.—Deflection and apparent displacement, with stringer formation.

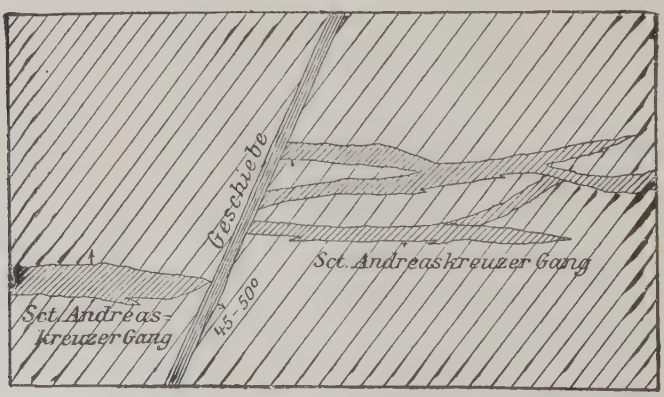


Fig. 81.—Deflection of an Andreasberg vein against an older vein with a scattering into stringers on one side only. (Zimmermann.)

try rock, the so-called vein slate, Gangthonschiefer, and sometimes with

solid fragments of graywacke. The construction of these Ruscheln is sometimes disclosed by mining operations. One, for example, the Fauleruschel, near Clausthal, was cut by a drift from the Kaiser Wilhelm, shaft II. Innumerable folds and crinkles were found within it, as well as many well marked slip or gliding fissures.[1] Similar conditions prevail in the 'Lettenkluft' (clay fissure) at Pribram, which is also a reverse fault, against which many of the veins are deflected, also in the 'Bar Flache' of the Himmelfürst mine, near Brand, a zone of barren crushed and altered material which cuts off a great many veins. It will be observed that this feature differs from the cutting off of a vein by a later fault. The mineral vein splits up or ends against the vein of crushed rock.

Fig. 82.—Complete splitting up into stringers of the Frisch Gluck Stehende on approaching the Peter Stehende in the Hoffnung Gottes mine. (Ground plan, after von Weissenbach.)

The deflection of dikes of eruptive rock by fissures is of very frequent occurrence. Fig. 83 represents the ground plan of a porphyrite dike cutting quartzitic slate, at Dovigfoss, near Aamot, in Norway. The dike is deflected several times by small quartz stringers. This dike is itself a branch of a larger dike, and it is clear that the course of the walls of this larger dike is also influenced by the quartz stringers.

The discussion of deflection naturally suggests and leads up to the subject of *displacements,* a feature which is most appropriately treated here,

[1] G. Köhler: 'Beiträge z. Kenntniss d. Erdbewegungen und Störungen der Lagerstätten,' *B. u. H. Z.* 1897, p. 217.

since many mineral veins are formed by the filling of fault, that is, displacement fissures.

(h) Displacements.[1]

By faulting we mean a change in the relative position of one block compared with the other, along a plane separating them. Such dislocations fall into two main groups: 1, faults or displacements produced by vertical

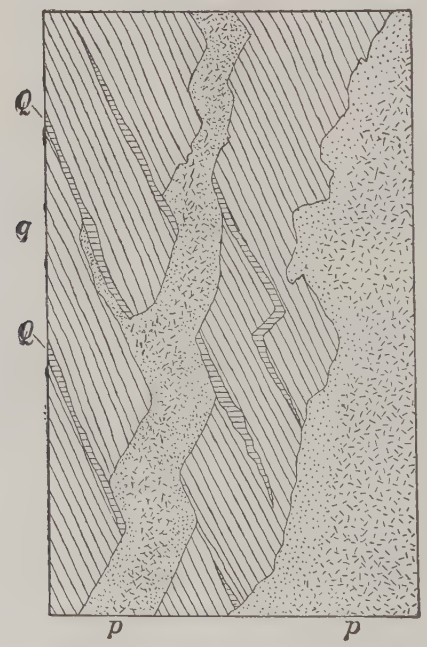


Fig. 83.—Dike of augite porphyrite in quartzose schist at Davigfoss. (Ground plan 1:15.)

q, quartzite slate; Q, quartz stringers; p, augite porphyrite, finely crystalline along the selvage.

movements; 2, faults produced by horizontal movements. The second group is the least frequent and least important. There is a possibility of

[1] A very full list of publications about the faulting of veins is given by F. T. Freeland, 'Fault Rules,' *Transactions* American Institute Mining Engineers, Vol. XXI, 1892, p. 491. The more important publications include: J. C. L. Schmidt: 'Theorie der Verschiebung älterer Gänge.' Frankfort, 1810. C. Zimmermann: 'Die Wiederausrichtung verworfener Gänge,' etc. Leipzig, 1828. R. von Carnal: 'Die Sprünge im Steinkohlengebirge.' Karsten's *Archiv n. F.* 1832, IX. H. Höfer: 'Die Ausrichtung von Verwerfungen.' *Oest. Z. f. B. u. H.*, XXIX, 1881, and XXXIV, 1886. G. Köhler: 'Die Störungen der Gänge, Flötze und Lager.' Leipzig, 1886. E. de Margerie and A. Heim: 'Die Dislocationen der Erdrinde.' Zürich, 1888.

combination of the two kinds of movement, and hence cases may arise which may not fit into these two classes.

(a) *Displacement Produced by Vertical Movements.*

This title implies movement along a vertical line. In most cases, however, the movement is not exactly vertical, but oblique. This kind of displacement can be subdivided into two classes: (a) Displacements pure and simple; (b) flexures. The first is caused by a fracture accompanied by a relative shifting of the two parts (Fig. 84); the latter is merely a bending or sharp flexure of a part of a layer or plate of rock (Fig. 85). If the

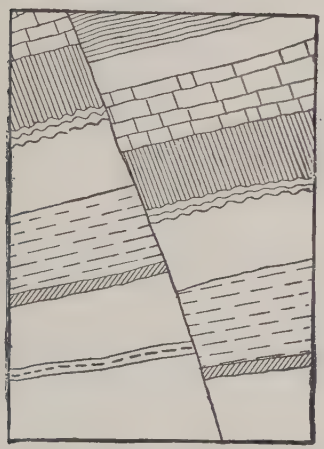


Fig. 84.—Simple fault (section.)

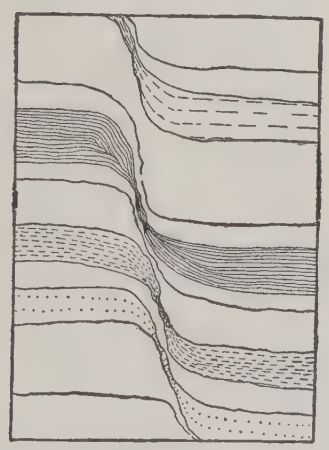


Fig. 85.—Flexure (section).

flexure is so sharp that rupture occurs, the flexure then becomes a true fault, accompanied by a drag of the ends of the strata on both sides (Fig. 86).

I. *General Properties of Simple Faults.*

A few definitions are needed as a preface to a discussion of faults. The distance between the faulted ends measured along the plane is the *displacement* or shift (*f* in Fig. 87). The distance along a horizontal plane between the ends of the faulted vein is called the *heave* (*w* in Fig. 87). The vertical distance between two displaced portions of a vein or bed is called *throw* or vertical downthrow (*s* in Fig. 87). It should also be remembered that the width of the fault fissure must be considered as a factor in discussing the heave of faults.

The horizontal projection of the fault plane is usually a straight line (Fig. 88); sometimes it shows curves, which are merely variations of the

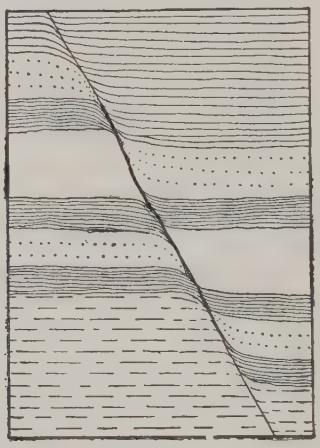


Fig. 86.—Section of a fault becoming a flexure.

general strike. In rare cases closed curves have even been observed (Margerie and Heim).

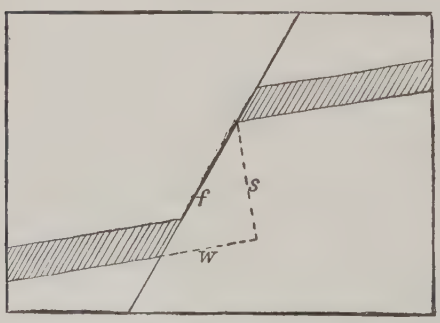


Fig. 87. —A displacement in profile.
f, displacement or shift; s, vertical displacement or throw; w, heave or horizontal displacement.

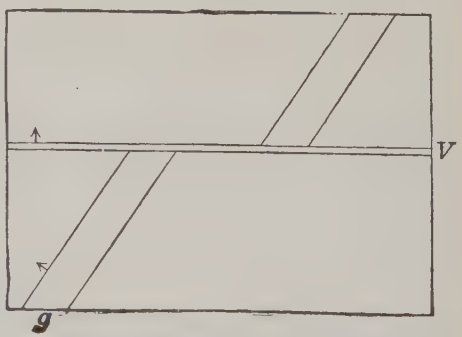


Fig. 88.—A faulting shown in ground plan.
g, displaced vein dipping northwest; v, fault fissure dipping north.

II. *Filling of Fault Fissures.*

A fault is but rarely a gaping fissure. It is usually filled either by more or less comminuted and ground up fragments of rock from both the walls.

or by mineral material subsequently introduced, which may include ore. Very frequently both rock rubbish and mineral deposits are present, especially in faults occupied by mineral veins.

We will first describe in some detail the mechanical fillings which are common in both barren and in ore-bearing fissures. This filling may consist of irregular, mostly angular blocks and fragments, sometimes subangular or even rounded. The material is often held together by a paste or cement of firmly compressed, finely triturated particles, or it may even be cemented together by a mineral deposit. Such *friction breccias,* as this kind of material is called, are sometimes quite thick. In the great Feldbiss fault of the Aachen coal basin, the breccia attains a maximum thickness of 12 m. (40 ft.). The mineral veins of Freiberg very frequently consist of a breccia of gneiss, with scattered stringers of ore. Such a structure is especially frequent in compound veins or lodes. At Freiberg, the spaces between the rounded blocks of gneiss are often filled by pebbles of greatly decomposed gneiss with ore veinlets between. The fragments of rock are often flat, and the slabs lie parallel to the walls. If these fragments exhibit the banding of the gneiss, it is generally seen that the direction of banding does not agree in the different blocks, and differs from that of the solid country rock. Similar conditions were described and figured by G. A. von Weissenbach at the Mächtigen Gang of the Gnade Gottes and Neujahrs Maasen mines at Johanngeorgenstadt, a vein occurring in altered schist (Fig. 89). As he graphically describes it, the schist "appears jammed to the side or somewhat displaced, one part over the other, in the same way that the fibres of wooden props in mines are seen to be jammed by the pressure of the rocks above and squeeze out in a plane at right angles to the axis of the timber."

Sometimes well-rounded fragments of the country rock lie scattered through a finely crushed mass, and by movement within the mass during faulting, and by contact with harder grains or with sharp projections of the fissure walls, they have been scratched and scarred exactly like the striated boulders of the ground moraines of a glacier. Such striated surfaces are especially well developed in the veins of the Himmelfürst mine near Brand. On the Bar Flache, distinctly scratched specimens of country rock were found. In the Daniel Flache, ground-up specimens of this kind occurred in the midst of a clayey mass 0.5 to 2 m. thick, formed by fragments of ore and gangue, and older vein[1] fillings.

Figure 90 represents a fault cobble showing distinct friction striae from the Neuglück Spat drift, No. 15, below adit. The cobbles lie either in the vein clay or among the pebbles of crushed gneiss, both along the walls and

[1] E. W. Neubert in *Freiberger Jahrbuch.* 1881, p. 63.

in the center of the lode. Such friction gravels when compacted and indurated form a conglomerate vein. In such cases the pebbles are sometimes packed close together, as on the Peter Stehende of Christbescheerung mine, near Freiberg. Sometimes they are incrusted over with mineral de-

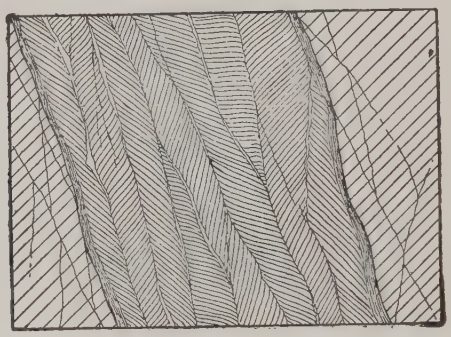


Fig. 89.—Section of a mineral vein near Johanngeorgenstadt. (Von Weissenbach.) Shows flat schist blocks parallel to the lode surface, with planes of schistosity running in various directions.

posits, as on the Eduard Spat of Himmelsfürst, where crystals of stephanite coat pebbles of mica schist. G. A. von Weissenbach[1] described such vein

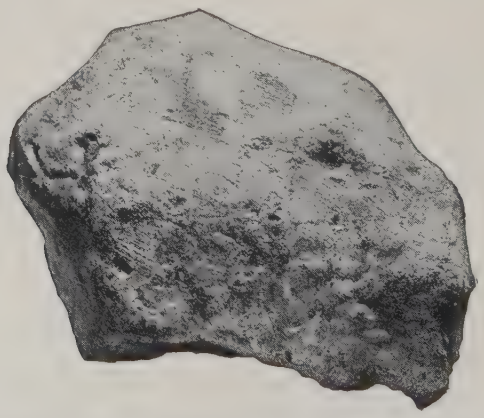


Fig. 90.—A fault cobble with scratches. From Daniel lode on Himmelsfürst. (A part broken off.) (From nature, two-thirds natural size.)

conglomerates under the term 'Kugelgestein' (ball rock) and very aptly compared the process of their formation by friction movement between the fissure walls to that observed in grinding-mills.

[1] 'Abbildungen merkw. Gang verhältnisse.' 1836, p. 18.

Such conditions are fairly common in the tin veins in quartz porphyry, at Altenberg in the Erzgebirge. The vein filling consists of hard balls of porphyry imbedded in a clayey mass composed of completely altered and ground-up porphyry. Similar formations are known in the Elias vein near Joachimsthal, and from the tin veins of Cornwall (Collins). S. F. Emmons[1] also mentions similar cases, but ascribes the rounding as often due to decomposition resulting from the action of mineral solutions acting upon fragments that had previously been angular. In Fig. 91, we give a picture, after G. A. von Weissenbach, of such a drag or conglomerate vein 10 centimeters (0.33 ft.) thick, which lies along the hanging wall of a vein at Luxbach near Annaberg.

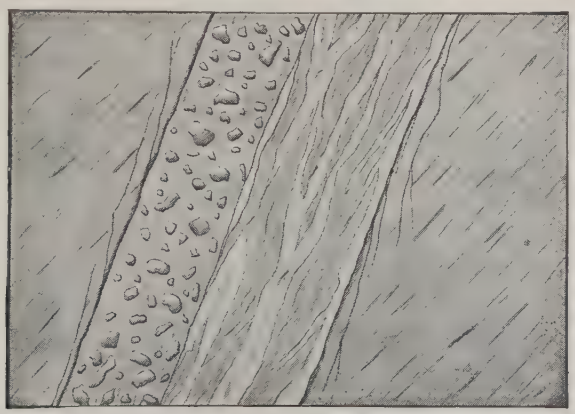


Fig. 91.—A conglomerate vein along the hanging wall of the Neu Unverhofft Glück vein, near Annaberg.

This attrition gravel of veins must not be confounded with those real gravels derived from overlying sedimentary strata, and which, in some cases, have fallen into open fissures, as shown later.

In connection with these vein gravels,[2] mention should also be made of the rare occurrence of rock fragments that have been twisted off cylindrically in fault fissures. The Freiberg mining school museum contains such a piece 15 cm. (0.5 ft.) long, as thick as an arm, and resembling the branch of a tree. It consists of a hard, brittle greisen from Altenberg, which, besides having two rounded faces of cross fractures, is completely covered with

[1] 'Structural Relations of Ore Deposits.' *Trans.* Am. Inst. Min. Eng., 1888, p. 19.

[2] This paragraph in the German original describes distinctions not used in America. The finer particles, consisting of fragments of the size of a hazelnut, and mostly quite soft as a result of advanced decomposition, constitute the secondary layer (ausschram, filings). The so-called Guhrs are still finer, forming a clayey gravel. Lastly we have the vein clays, which are very common, and represent the finest product of rock comminution.

slip striae running obliquely around it. These gliding surfaces (Fig. 92) are even at one point involute, that is to say, two of them follow at a little distance, one over the other, in such way that the slip planes intersect at acute angles. Such peculiar specimens are formed when an upright fragment of rock is dragged between the two walls of the fault fissure in a direction parallel to the longer axis of the fragment, while at the same time it is moved about or revolved about this axis.

Fig. 92.—Drawn-out cylinder of greisen fragment from a fault-cleft at Altenberg.

The *vein clays* are soft, pasty or tough, plastic clays, frequently mixed with larger grains, and often colored black by carbonaceous material. In the blackish vein clay of Verespatak and Maidanpeck, the so-called 'Glamm,' the coloring, according to E. Tietze,[1] is due to copper oxide. Posepny's[2] view that the Hungarian 'Glamm' has been washed into the fissures from the surface seems improbable, and it appears more likely that this material is the result of trituration and decomposition, and was either formed in the lode fissure itself or forced into it from greater depth, as will be explained later on.

[1] E. Tietze: *Jahrb.* d. k. k. Geol. Reichsanst. 1870, p. 321.
[2] F. Posepny: *Idem.* 1867, p. 101, and 1870, p. 273.

Sometimes such a vein clay shows a distinct slaty or schistose structure, due to strong pressure. Such material separates along these cleavage planes into scales which are often as smooth as glass or are covered with parallel friction striae. Such vein clay slates from lodes of the upper Harz, described in detail by A. von Groddeck,[1] are mechanically altered Culm clay slates, which have undergone, especially the variegated varieties, a chemical transformation, as noted later.

The finer pebbles (ausschram) and the clays are often confined to a narrow zone along the wall, in which case they form the clay selvage or gouge. Such a clay selvage is ordinarily welcome to the miner because it facilitates the loosening of the true vein filling from waste material, while the work is more difficult when the lode is "coalesced with the country rock" by crystalline crusts, as the German miner puts it, or "frozen hard to the country," as the American miner picturesquely expresses it.

These friction products are workable when they are impregnated with finely disseminated ores, which are mostly of secondary (*i. e.*, later) origin. In the Erzgebirge such vein clays are colored yellowish, reddish or brownish by metallic compounds, being known as gilben (mountain yellows) or braunen (browns). At Freiberg, in the Thurmhof vein, a yellow vein clay with 0.062% of silver was formerly mined, while in the Friedrich vein the yellow vein clay held scattered particles of wire silver and grains of earthy silver glance, so that the clay contained 1.6 to 1.9% silver. In the Annaberg area, according to H. Müller,[2] these vein-clays often contained a considerable amount of silver, so that they paid to work in the Himmlisch Heer. Black clays containing as much as 5% in silver were also extracted there. [At Butte, Montana, the fault clays often contain ore particles and the filling sometimes consists of balls of pyritic ore, bornite, glance or enargite, quartz and altered granite, so that the entire mass is workable. The black clays often contain as high as 8% copper, but are not mined alone.] Mention must also be made of the fine crystals of native gold in clay of the Farncomb Hill veins of Summit county, Colorado, described by Rickard.

The description of the mechanical material filling fault fissures and the impregnations just mentioned naturally precedes an account of the fault fissures which form mineral veins.

III. *Fault Veins.*

Mineral veins are often true faults. In the Freiberg area it is seldom that this can be shown by a comparison of the rock of the two walls, be-

[1] A. von Groddeck: *Z.* d. D. g. G., 1866, Vol. XVIII, p. 693 and 1869; Vol. XXI, p. 499, and *Jahrb.* d. k. preuss. geol. Landesanst., 1885, pp. 1-52.

[2] 'Die Erzgänge des Annaberger Revieres.' Leipzig, 1894, p. 96.

cause the rock is of very uniform nature, but it is frequently demonstrable when the fault veins cut through older veins.

A good example in which the faulting can be shown by the rocks is seen in the Himmelsfürst mine near Brand, where the Benjamin Stehende cuts through and displaces bands of muscovite gneiss and mica schist intercalated in biotite gneiss; the fault-vein is itself displaced by another mineral vein, the Neuglück Spat (E. W. Neubert, MSS.).

The lodes of the upper Harz are, as is well known, fault veins in which the dislocation is very clearly shown by the different beds of the Devonian and Culm (carboniferous) formations. At Bockswiese and Lautenthal the veins have a Devonian footwall, while the hanging wall is formed of rocks

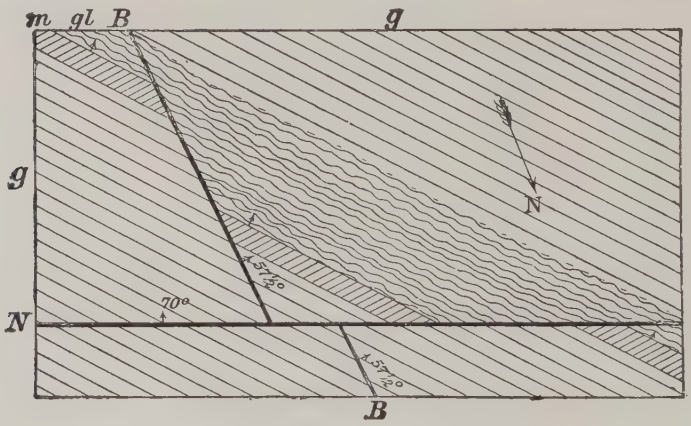


Fig. 93.—The Benjamin fault vein of Himmelsfürst. (Ground plan.)
B, Benjamin Stehender; N, Neuglück Spat; g, biotite gneiss; m, muscovite gneiss; gl, muscovite schist.

belonging to the Culm. The throw, according to A. von Groddeck,[1] is 200 meters. Fig. 94 (after E. Maier[2]) shows a cross-section of the displacements of Paleozoic strata produced by the main Bockwieser (Pisthaler vein and the Grünlindener vein).

Good examples of silver veins filling fault fissures displacing Carboniferous strata occur at the Enterprise mine, Colorado, and have been described by T. A. Rickard.[3]

Even where the uniformity of country rock prevents a direct recognition of displacement along mineral veins, the dislocation may often be inferred

[1] 'Lehre,' etc. 1879, p. 229.

[2] '*Beitrage* zur Geol. des Bockwieser Ganggebietes.' Diss. Ber. d. Naturf. G. zu Freiberg, 1900, Vol. X, p. 2.

[3] T. A. Rickard: 'The Enterprise Mine,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXVI, pp. 906-980.

from other observations. Thus the local widenings of veins have been explained since De la Beche's[1] time as the result of dislocation of the vein walls and due to their projections and irregularities. The accompanying Fig. 95 illustrates this shifting of irregular walls, which must necessarily produce prismatic or lenticular cavities. Le Neve Foster[2] uses the same theory to explain the peculiar pipe veins in some Cornwall mines, and Th.

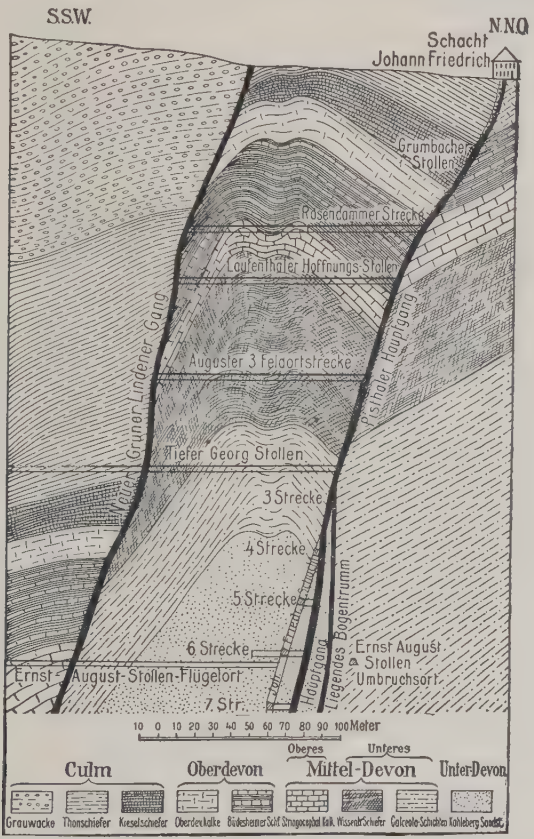


Fig. 94.—Cross-section of displacements of Paleozoic strata. (E. Maier.)

Kjerulf[3] has endeavored to explain the genesis of the Norwegian 'rulers' (erzlineale) in the same way.

IV. *Condition of Fault Walls.*

The sliding motion of one side of a fault over the other, and the conse-

[1] 'Researches in Theoretical Geology,' 1834, Chap. 10, and 'Report on Geology of Cornwall,' 1839, p. 317.

[2] *Trans.* Roy. Geol. Soc. Vol. IX, 1876.

[3] 'Geologie von Norwegen,' Trans. by Gurlt. 1880, p. 294.

quent rubbing of the walls, produces smooth and evenly polished faces. Such polished surfaces are called slickensides and sometimes show truly mirror-like surfaces, if the material itself has a metallic luster, as, for example, the magnificent mirrors of pyrite found in the Confesionario mine (Huelva) or of galena of Incurtosi (Iglesias, Sardinia). Similar examples may have led the Aztecs to make their remarkable pyrite mirrors. In other cases, numerous parallel scratches are seen on such polished surfaces, either as delicate striae or relatively deep furrows. An example of this kind from the Lade des Bundes lode at Himmelsfürst, near Brand, in which the striations are cut in galena, is shown in Fig. 96. Wherever these features occur they indicate that the fault fissure was not an open one during the move-

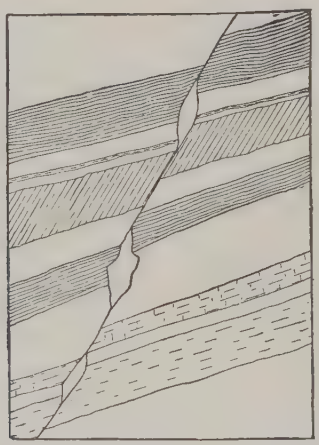


Fig. 95.—An explanation of local vein-widening from a fault.

ment. The direction of the striations on the vein wall is supposed to represent the direction in which motion has taken place, but one must not assume that they are always parallel to the dip of the fault fissure. This is by no means the case, as has been shown by H. Höfer. This view (at one time generally prevalent) arose from the Schmidt-Zimmermann fault rule, according to which the rocks in the hanging-wall of the displacement fissure slid down parallel to their former position. This rule does indeed hold for many cases, but it is by no means universally valid.

Fault striations often form an acute angle with the line of dip; indeed, cases occur where they are almost perpendicular to the dip. Such a condition, for example, has been described by H. Höfer from the ironstone mine, near Ober-Zeiring, near Judenburg, in Styria, and from the Hodritsch lode area near Schemnitz in Hungary. In the fault fissures of the upper Harz

region the fault slips or gliding planes show horizontal striae, as has been known since Fr. Ad. Romer's time. Finally, very fine instances of horizontal friction striations several meters long have been observed by the present author in the main great fault in the sandstone of Lusatia.

The direction of fault striae is not always the same over the entire wall of the same fault fissure.

Numerous deviations occur and several systems of lines and furrows may even cross, and in one cluster of many parallel faults the striae may have various directions on different surfaces.

The striations are not always straight. The slipping may have taken place in rapidly varying directions, and in such cases the striae may form curiously winding curves, as in the specimen exhibited before the Naturalists' meeting at Vienna in 1892 by Ed. Suess.

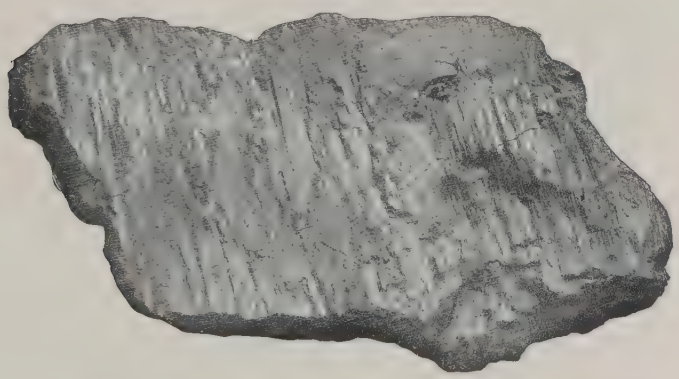


Fig. 96.—Striated surface of galena from Lade des Bundes lode in Himmelsfürst mine. (From nature. One-fifth natural size.)

In this case the intricately tangled scratch lines showing on a polished fault plane surface of black calcareous slate, from Radotin in Moravia, were evidently caused by minute but hard projecting points of the opposite wall of the fault fissure. This is borne out by the complete agreement of the various scratch figures (reproduced in Fig. 97 from a self-printed plate, with the kind permission of the discoverer, J. J. John, and the first describer, Ed. Suess). Suess very appropriately styled the specimen a natural earthquake autograph, for it may readily be imagined that its formation was due to an earthquake tremor.

In other cases it is probable that the curved scratches were produced by hard grains and fragments present in the fissure filling itself, and not by a projection of the opposite walls. Intersecting striations can also be pro-

duced by a change of position of the rock fragment, while it was pushed along in the fissure.

The reader is cautioned not to assume that the length of the striation represents the extent of the movement. On the contrary, the length of such a scratch represents in most cases the combined length of the scratched surface and that of the dislocation (movement). It is only in rare cases that such a scratch can be supposed to be caused by a single hard grain, that is

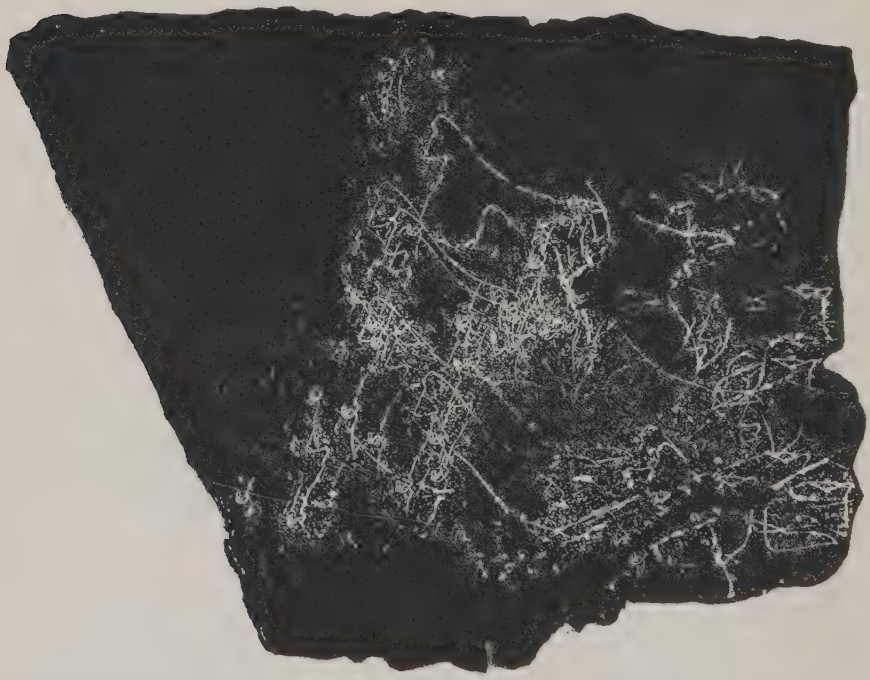


Fig. 97.—Earthquake autograph, gliding surface with intricately tangled striae on limestone from Radotin. (A print from the stone itself.)

to say, geometrically speaking, by a single point over which the surface was drawn.

All these considerations show that these "handwritings on the wall" (Rickard) cannot always be deciphered as easily as might seem at first sight. At any rate, a test made by H. Höfer seems to apply to many cases. If, in passing the hand over an extensive gliding plane, you receive the impression of perfect smoothness, your hand has been moving in the direction in which the opposite rocks moved; if you feel any roughness the hand is moving opposite to the rock movement. The reason is that the gliding planes

have the same relief on a small scale as the glacier-polished surfaces of rocks, as is shown in the following diagram (Fig. 98). In this diagram, ground-up material has been indicated as filling the fault fissure. Such material may, however, be practically absent.

When a fault passes transversely through thinly bedded rocks the edges of the strata are often bent downward (or upward) in the direction of the movement. In some veins the walls of the open fissure may have been coated with mineral crusts which remain intact on one wall, while along the other the mineral crusts were broken by later fracturing and the ends of the beds bent around (Fig. 99).

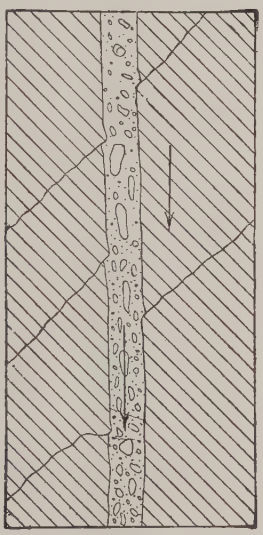


Fig. 98.—Ideal section of a fault fissure to illustrate Höfer's rule. (The displacement and grinding took place in the direction of the arrows.)

V. *Torsional or Turning Movement During Displacement.*

A consideration of slip surfaces or planes, whose striation is not always coincident with the dip, shows that the Schmidt-Zimmermann rule has many exceptions. In these exceptional cases the dislocation sometimes may be inferred from observations of a different kind.

H. Höfer has properly revived an observation communicated long ago by J. F. W. von Charpentier.[1] In the Himmelsfürst mine, near Freiberg, at the junction of a Morgengang with the Schneider vein, 120 feet below the deep level of that locality, the two veins intersect without change of

[1] 'Beobachtungen über die Lagerstätten der Erze.' Leipzig, 1799, p. 103.

either strike or dip. On the contrary, 240 feet lower, the course of the Stehende vein changes at its junction with the Morgan vein, and a so-called dragging of both lodes could be noticed. This is also observed at a depth of 360 feet, except that there the union of the two lodes is maintained for a greater distance than in the first instance. Thus the ends of the faulted vein on opposite sides of the fault approach each other in depth, and actually meet 120 feet below the drift. This proves that the displacement is not parallel, but due to a twisting (torsional) movement. Similar examples have been recently found in various places. In the Freiberg area a turn or twist of this kind is shown in the displacement of the Peter Stehende of the Alta Hoffnung Gottes mine. This vein is dislocated by the Flache fissure, dipping 70° east. In the upper part, the two sections thus formed (the northern of which is entered on the maps as Einigkeit Morgen-

Fig. 99.—Section of a fissure with sharply cut footwall, while the hanging wall shows the strata bent.
a, older ore-bearing stringer; b, younger friction breccia.

gang) are rather far apart. The distance between them along the Flache fissure is 13 meters; in the counter drift, only 11 meters; in the seventh, only 5; in the ninth, 0. Thus if we could see a considerable extent of the striations and slickensides of the fault-wall, they would represent segments of a circle.

Among more recent examples may be mentioned the great displacement called Münstergewand Feldbiss, near Aachen, which, according to Höfer, is connected with a distinct twist. [Also at Butte, Montana, the great Anaconda vein is displaced several hundred feet vertically by a fault showing a torsional movement.]

VI. *The Surface Evidence of Displacements.*

A fault does not usually show as a cliff or wall on the earth's surface. That it does so at first is evident, and scarps are formed by fissures due

to the sinking of the earth's surface as a result of coal mining, but such superficial scarps though sharply accentuated at first are very quickly leveled by the rainfall. In the first stage of this leveling process trench-like depressions are often formed as the rainwater washes away the loose material filling the displacement fissure, and a secondary subsidence thereupon occurs near the surface, as shown in Fig. 100 and 101. Such a section is often shown by faults resulting from coal mining, provided the fissures have a favorable dip.

Fault scarps do sometimes form natural features, especially in dry countries where erosion makes but slow progress, as, for example, the displacement scarps of the Colorado plateaus described by Powell. In most cases, however, all traces of the fault scarp are quickly effaced and merely indirect topographic indications are presented; such as the course of brooks that have followed a fissure, or a line of springs along the displacement. If, on the contrary, the fissure is filled with loose, permeable material it may gather the ground-water from afar, become completely saturated in its lower portion, and give rise to dangerous outbreaks of water in mines. Though a displacement may not be indicated topographically, yet in most cases it can be detected by the interrupted or diverted course of the rock outcrops.

VII. *Different Kinds of Simple Displacement.*

If we include displacements of sheets and beds with those of veins, we may distinguish the following cases based on the relation of the down-thrown block to the strike:

1. *Strike* faults, or longitudinal displacements in which the course or strike of the fault coincides with the strike of the strata or of the lode (Fig. 101 and 103). Two cases are possible, (a) normal faults dipping toward the down-thrown block (Fig. 102), (b) reverse or overlap faults in which the opposite is true (Fig. 103). Strike faults of tilted beds are recognized on the earth's surface by repetitions of the outcrops of the different beds, often with omission of several members, as shown in Fig. 104.

2. *Cross* faults striking at or near a right angle with that of the displaced blocks (Fig. 105 and 106).

3. *Acute angled* or *diagonal* faults, in which the course of the fault forms an acute angle with the strike of the displaced block. (Fig. 107 and 108.)

Furthermore, displacements may be classified in accordance with the relative direction of displacement of the thrown block. According to this we have three cases:

1. *Normal or gravity* faults are ordinary dislocations in which the hanging wall block has slipped down along an inclined fault plane; according to

the Schmidt-Zimmermann rule this takes place in the direction of the dip and the two displaced blocks maintain a parallel position. As shown on p. 151, this rule has many exceptions. In plan the faulted beds occupy more space horizontally than they did before dislocation, *i. e.*, an area greater by the amount of the horizontal throw than its original area (extension dis-

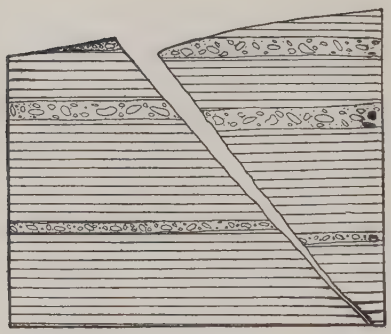


Fig. 100.—Recent displacement fissure unchanged by rain-water.

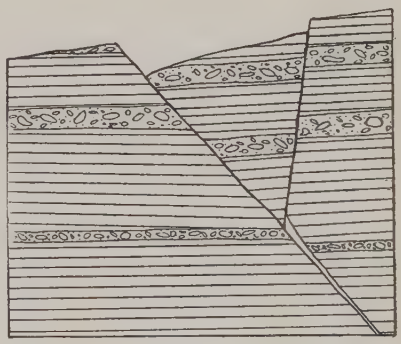


Fig. 101.—The same with a block dropped down.

placement of Margerie and Heim). Most faults belong to this first group. (Fig. 109.)

2. *Vertical* faults. In these the effect is the same whichever side is downthrown (Fig. 110).

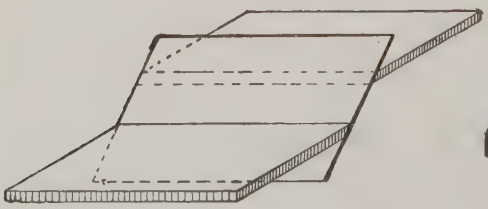


Fig. 102.—Model of a normal strike fault.

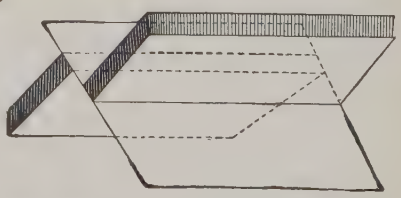


Fig. 103.—Model of a reverse or overlap displacement.

3. *Overthrusts* or *reverse* or *overlap* faults, when the hanging wall block has been shoved upon the block that lies beneath the fault plane. As this is accompanied by a compression of the beds, so that they occupy a smaller space than before, this might, following Margerie and Heim, be called a compression displacement. (Fig. 111.)

Very fine examples of overthrusts are found near Johannesburg in the Transvaal, where the beds of gold-bearing conglomerate are dislocated by

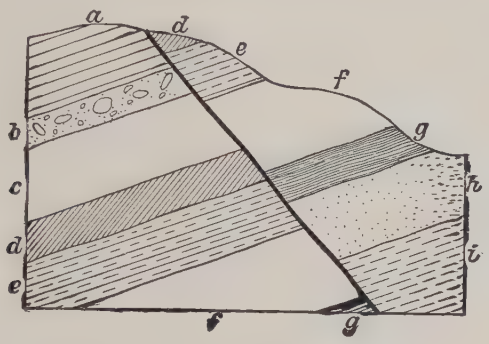


Fig. 104.—Section of a strike fault.

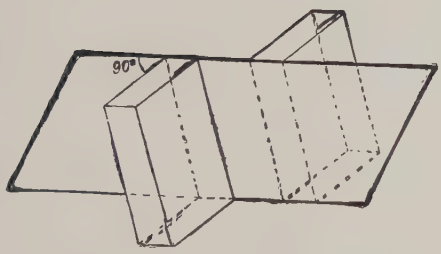


Fig. 105.—Model of a cross fault.

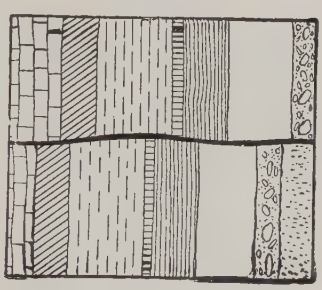


Fig. 106.—Plan of a cross fault

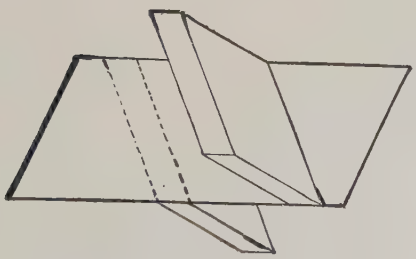


Fig. 107.—Model of diagonal fault.

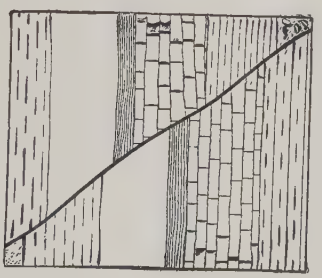


Fig. 108.—Plan of a diagonal fault.

several overlap faults. (Fig. 112.) This example also proves that overthrusts, though common in strongly folded mountain ranges, can and do occur in regions of open and comparatively slight folding.

Overthrusts may also occur along vein fissures, as, for example, in the ore-bearing lode of the Gute Hoffnung mine, near Werlau on the Rhine, and in the Schwebende of the upper Erzebirge in Saxony.

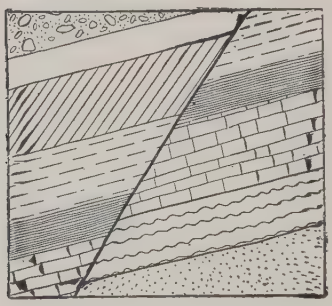


Fig. 109.—Normal displacement. (Section.)

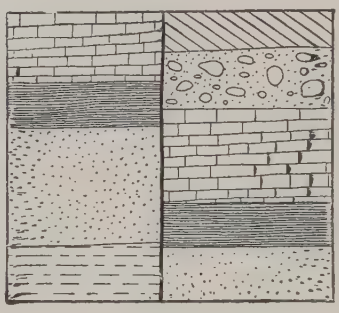


Fig. 110.—Vertical displacement. (Section.)

VIII. *Special Types of Displacements.*

Many displacements are the result not of a single fault with down-throw or overthrust, but of a series of parallel fault fissures with successive displacements in the same direction. Groups of such faults, all in the same direction, are termed *step faults* or *distributed faults.* A good example is the great trunk fault, known as the "Rother Ochse," which traverses the

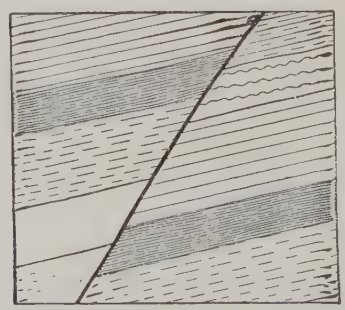


Fig. 111.—Overthrust fault. (Section.)

northeast flank of the Permian coal basin in the Plauen basin near Dresden. At Zschiedge, R. Hausse calculated the total throw of the many individual faults as 350 m. (1,148 ft.). Many partial faults have produced a complete chopping up of the main coal seam, since the brittle coal breaks

into slabs and blocks that can readily turn about in the rather soft country rock.

The coal miners of Germany designate the thin blocks or slabs dropped down by step faults, or lying between two parallel faults, as *graben* (moat). Good examples of this character of displacement occur in the Mansfeld copper shales. In the vicinity of the veins such dislocations are naturally quite rare.

A block that has remained stationary between faults is called a *horst* (upthrust), or if narrow and long, it is called a *Rippenhorst*.

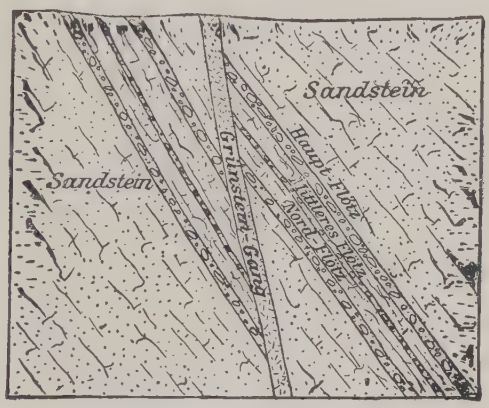


Fig. 112.—Reversed faulting of the gold-bearing conglomerate measures of the May Consolidated mine near Johannesburg. (Schmeisser.) (Section.)

IX. *Simple Displacements.*

Displacements that are perfectly apparent occur when a vein of considerable thickness passes diagonally through another, as illustrated in Fig. 113.

X. *On the Location of Faulted Parts of Veins.*

1. Before assuming that a displacement exists when a vein is lost in a mine working, its possible deflection must be considered, viz.: Whether the lode has not merely changed its direction and followed an older fissure. This supposition would be proven true if stringers occurred in the filling of the supposed fault fissure. These stringers would then have to be followed by an exploratory drift in order to locate the extension of the deflected lode beyond the transverse fissure.

2. If the vein is not deflected, but is actually displaced by a younger fissure, the first thing to do is to look in the fault filling for fragments broken off from the dislocated vein. If such fragments are entirely wanting on one side of the vein, while on the other they occur in a cluster, or fan, or are strung out along the fault forming a fan or string, a drift should be driven along the fault in this second direction (Fig. 114). It should also be noted that in a faulted bed the bending or change of dip next the fault may indicate the direction of the movement. It points in the direction the sheet has been moved. (See Fig. 99.)

3. If fault striations are found on the fault wall their character and direction will often enable one to correctly infer the direction in which the missing part of the lode has been moved. By passing a hand over the slick-

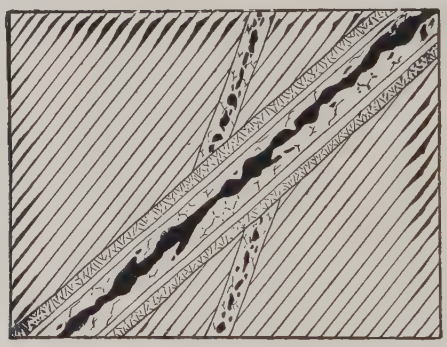


Fig. 113.—Displacement of a vein by a younger vein passing through at an acute angle. (Ground plan.)

ensides one may ascertain whether there exists a difference in the roughness, as set forth on page 150. The opposite wall has been moved in the direction in which the wall feels smoother.

4. If in a lode the hanging wall strata differ from those of the footwall, it may be assumed that the displaced portion of the lode has been moved downward. If the faulted vein has unlike rocks on opposite sides (contact vein) the drift should be driven across the fault to determine the nature of the rock at that point. If the hanging wall country is found across the fault the throw is normal and the displaced block has moved down. This rule is even more important in stratified deposits, and for this purpose a carefully made section of the overlying and underlying beds should first be made.

5. If the faulting is in a district where several other faults occur, which have been accurately located and their characteristics known, the new case

should be treated as analogous to those already known, for ordinarily in the same vein district the faults all show movement in the same direction. This, according to H. Höfer, is especially true for the lateral displacements along many faults, which may be alike over an entire vein area; thus according to H. Höfer, in the ore district of Littai in Carnicia they are left-sided; at the western Harz they are right-sided. At Chañarcillo, according to Moesta, they are left-sided.

6. When special indications of this kind are lacking it is necessary to attempt a graphical solution of the problem by means of a diagram based on geometrical principles. For such cases the Schmidt-Zimmermann rule is used, a rule which in practice is found to be true in the majority of cases. The procedure is as follows:

Fig. 114.—Fragments of the cut-off lode in the clayey filling of a displacement fissure as guide in tracing the lode.

First construct the projection of the line of intersection of the vein and the fault fissure. An example will show how this is done in a simple case:

Two intersecting veins, A S and B S, meet at S on the floor of a drift. The vein A S dips at the angle γ_1, the lode B S at the angle γ_2, γ_1 being larger than γ_2 (see Fig. 115). From point S measure any equal distance along each lode, S C and S D, and erect perpendiculars at points C and D. At the point S draw on S C the angle $90° - \gamma_1$. At point S draw on S D the angle $90° - \gamma_2$. Through the intersections E and F of these lines with the perpendiculars at C and D draw parallels to the corresponding vein, namely, through E parallel to A S, and through F parallel to B S. The two parallels intersect at the point G, which connected with S represents the line of intersection of the two lodes.

The line of intersection in the case of normal displacement is situated within the obtuse angle; in the case of left-handed or reverse displacement it is within the acute angle, and is always closer to the vein having the higher dip.

Having constructed the projection of the line of intersection, the following general rule is followed in order to find the missing vein:

The displaced lode is to be sought beyond the fault within the *obtuse* angle between the line of intersection and the fault.

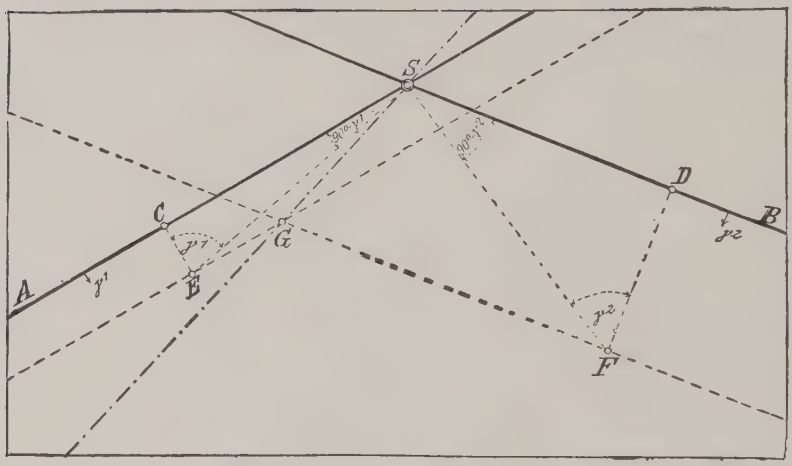


Fig. 115.—Construction of the line of intersection. (Explanation in the text.)

In Fig. 116, for example, a lode has been cut off at B by the fault VV_1. KK_1 is the line of intersection between the two. The direction of the arrows indicates the direction in which the fault block must be sought following along the fault.

For the better understanding of the rule we reproduce a portion of the plan map of the Himmelsfürst mine, near Brand (Fig. 117), showing the actual recovery of the Silberfund vein which was faulted by the Neuglück vein at I. The dotted line indicates the projection of the intersection, which was drawn from the known intersection on the Halbvierzehnten level through the points II and III, intersections known in the higher drifts and projected on the map. The Neuglück vein was followed along its hanging wall, according to the rule, in the direction of the arrows a-d, and the Silberfund Stehende was actually recovered a short distance away. At point II the situation was more complicated because the vein was first faulted by a

parallel fissure of the Neuglück Spat, and then once more by the latter itself. Hence at point II it was necessary to apply the rule twice in succession.

XI. *Displacements Due to Horizontal Movement.*

It has already been shown that in true faulting lateral movement is an occasional but a subordinate feature. We now take up a small group of faults in which a transverse horizontal displacement is the predominant feature. They are termed simple *shifts* (Verschiebungen), and the steep dipping fault planes along which horizontal movement takes place may be called slip planes (Blätter leaves).

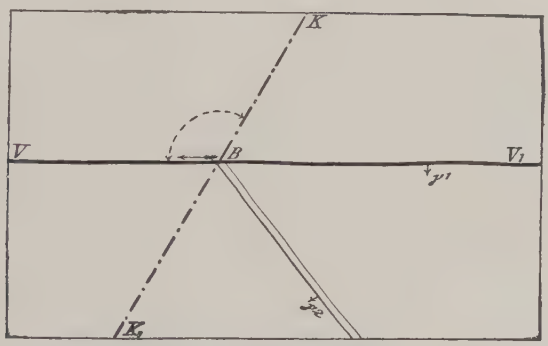


Fig. 116.—Diagram to illustrate the rule for tracing displacements.

G. Kohler has described shifts of this kind from several lodes in the Harz, such as the Samsoner lode at St. Andreasberg (Fig. 118) and the Altensegener main lode. They are still commoner in stratified deposits, as, for example, in the Rammelsberg ore deposit.

In the recovery of faulted and shifted veins, rules 1 to 5, given for ordinary faults, apply in a slightly changed form.

(i) Fissure Formation.

Fissures are planes of disruption; hence dicission spaces (from discindere, to tear apart) must be discriminated from the cavities formed by the leaching action of water on readily soluble rocks, called dissolution spaces by F. Posepny. Fissures sometimes show clear proof of strain and shear (or a tearing apart) in the distorted fossils found in the country rock immediately adjoining. Such phenomena have been described by Harkness from the vicinity of Cork, and their significance discussed by Daubrée.

In some cases the fissures are formed by forces originating in the ruptured rock itself; in such cases the fractures are usually confined to this particular rock mass, occasionally passing outside for a few yards. This type

Fig. 117.—A portion of the ground plan of the Himmelsfürst mine near Brand with the displacement of the Silberfund Stehende.

of fracture, called *entokinetic* fissure (A. W. Stelzner), falls into two subgroups. In the first, the fractures are contraction fissures due to a diminution of volume of the rock mass as a consequence of cooling or drying (cooling fissures and drying fissures). The second type originates through an

increase of volume in consequence of the absorption of water or some other chemical process as in serpentinization (dilation fissures of A. W. Stelzner). To a much wider extent fissures result from general mountain building forces, and may then be called, following Stelzner, *exokinetic* fissures. Many fissures cannot be readily classed in any of these groups because they are due to complex causes.

A. Daubrée[1] calls all disruption fissures lithoclases, and makes a further distinction between simple joints (diaclases), that is to say, fissures without demonstrable displacement, and paraclases, that is, fissures with displacement.

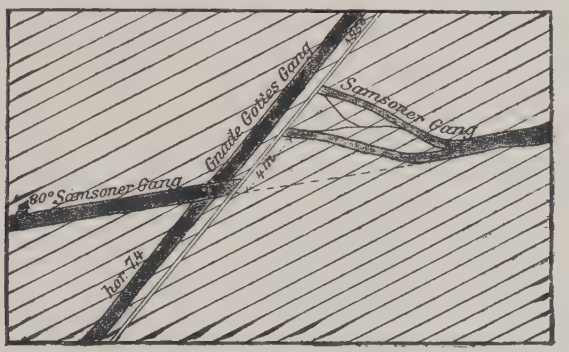


Fig. 118.—Shifting of the Samsoner lode in drift 41 at St. Andreasberg. (G. Kohler.) (Ground plan.)

The classification adopted and the nature of the formation of fissures will be rendered clearer by a number of examples:

a. Entokinetic Fissures.

I. Contraction Fissures.

1. *Cooling Fissures.*

It is well known that eruptive masses after cooling and solidifying from a molten condition are commonly traversed by numerous contraction cracks, which are often quite regular in occurrence, producing the characteristic columnar, laminated or spherical structures, while in other cases the fractures occur without any recognizable order.

Mineral veins resulting from the filling of such cooling (contraction) fissures are represented by the flat tin veins in the Zinnwald granite dome

[1] 'Synthetische Studien zur Exper. Geologie.' German translation by Gurlt. 1880, p. 234.

of the Erzgebirge. That granite masses are traversed by spherical contraction fissures due to cooling, which often conform approximately to the gently rounded surfaces of the hills, is a well-known fact. In quarrying out slabs for sidewalks from the granite quarries of Bautzen these fissures are often of great practical importance,[1] because along them even the fresh, unaltered, unfissured rock may be readily wedged into slabs. At Zinnwald such fissures were apparently filled with the gangues and ores of the tin formation, especially quartz, lithia-mica, tin-stone and wolframite, at a time when the cooling had not yet been completed. As shown in the cross-section, Fig. 119, these veins have the form of a pile of inverted saucers, the superimposed veins being near together. Eleven of them are being worked in the granite itself. A few very low grade ones were also found in the Teplitz quartz porphyry, into which the flat granite dome has penetrated from below.[2]

A case in direct contrast to this example of fissure formation is found near by in the mines of Altenberg, where a granite stock is traversed by innumerable small fissures utterly irregular in course, from which the rock has been enriched with tin ore. These fissures, together with their impregnation zone, form, as a whole, the so-called Zwitterstock (tin ore stock). Most of them are probably simply fissures of cooling.

On the other hand, it is difficult to decide whether the network of lodes in the propylites of Hungary is or is not due to fissures of cooling, though the fact that the veins of that region also occur in the adjoining Eocene sandstone is against the cooling theory. The mineral veins of Nagyag, however, are not fissures of contraction, according to B. von Jukey.

If an eruptive dike is fractured on cooling by a succession of transverse fissures occurring close together they form a so-called ladder vein (Leitergang). A well-known example of this is found in the Waverly mine at Victoria, Australia, where a dike of decomposed diorite is traversed by numerous stringers of gold-bearing quartz. Some of them are forked, and most of these stringers stop at the selvage, though a few continue a short distance into the adjacent slate[3] (Fig. 120).

In the same way, according to Th. Scheerer, a granite dike cutting through mica schists at the Näsmark mine at Thelemarken, Norway, is itself cut by numerous transverse stringers of quartz containing copper ores, and accompanied, according to J. H. L. Vogt,[4] by zones of greisen.

[1] O. Herrmann: 'Steinbruch's industrie und Steinbruch's geologie.' Berlin, 1899, p. 112.

[2] K. Dalmer: 'Erläuterungen zu Sect. Altenberg-Zinnwald der geol. Special-karte von Sachsen.

[3] As a result of the cooling of the highly heated contact zone.

[4] *Zeit f. Prak. Geol.* 1895, p. 149.

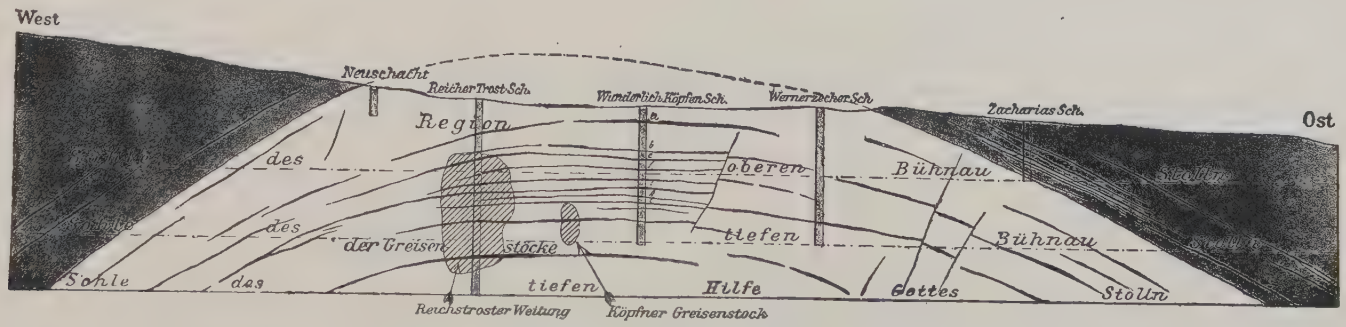


Fig. 119.—Ideal cross-section through the Zinnwald granite stock. (H. Zinkeisen.) Scale 1: 4000.
a, superficial seam; b, upper seam; c, organ seam; f, middle seam; i, pyritic bed; k, promising seam; l, ore stringer.

Typical ladder lodes are also seen in the gold-bearing quartz stringers of the dikes of fine-grained granite cutting schistose rocks at Berezovsk, near Ekaterinburg in the central Ural.[1] A part of the plan of the working of the mines of that locality (given in Fig. 121) shows the many short side drifts run after the gold stringers, all starting from main levels driven along the body of the dike (Polo). This plan gives a clear idea of the arrangement of these cooling (contraction) fissures, which but rarely extend into the country rock (Fig. 121). Exactly the same phenomenon is found elsewhere in the Ural in the diorite and serpentine dikes of Pyschminsk.[2]

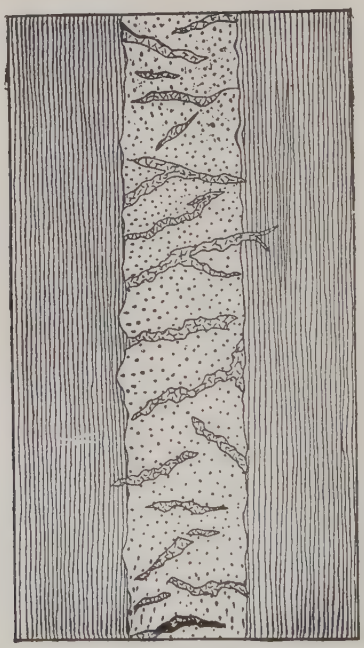


Fig. 120.—Section showing a diorite dike at the Waverly mine, Victoria, with a ladder vein of gold quartz. (Phillips-Louis.)

II. *Desiccation Fissures.*

That fissures may be formed by the drying of sedimentary rocks is well known, but it is difficult to prove in individual cases that veins have this manner of origin. The small fissures in the spherosiderite nodules of the

[1] 'Die Golddistricte von Beresow u. Mias am Ural.' *Archiv f. Prak. Geol.*, II, 1895, p. 499.

[2] F. Posepny: 'Genesis,' etc., p. 102.

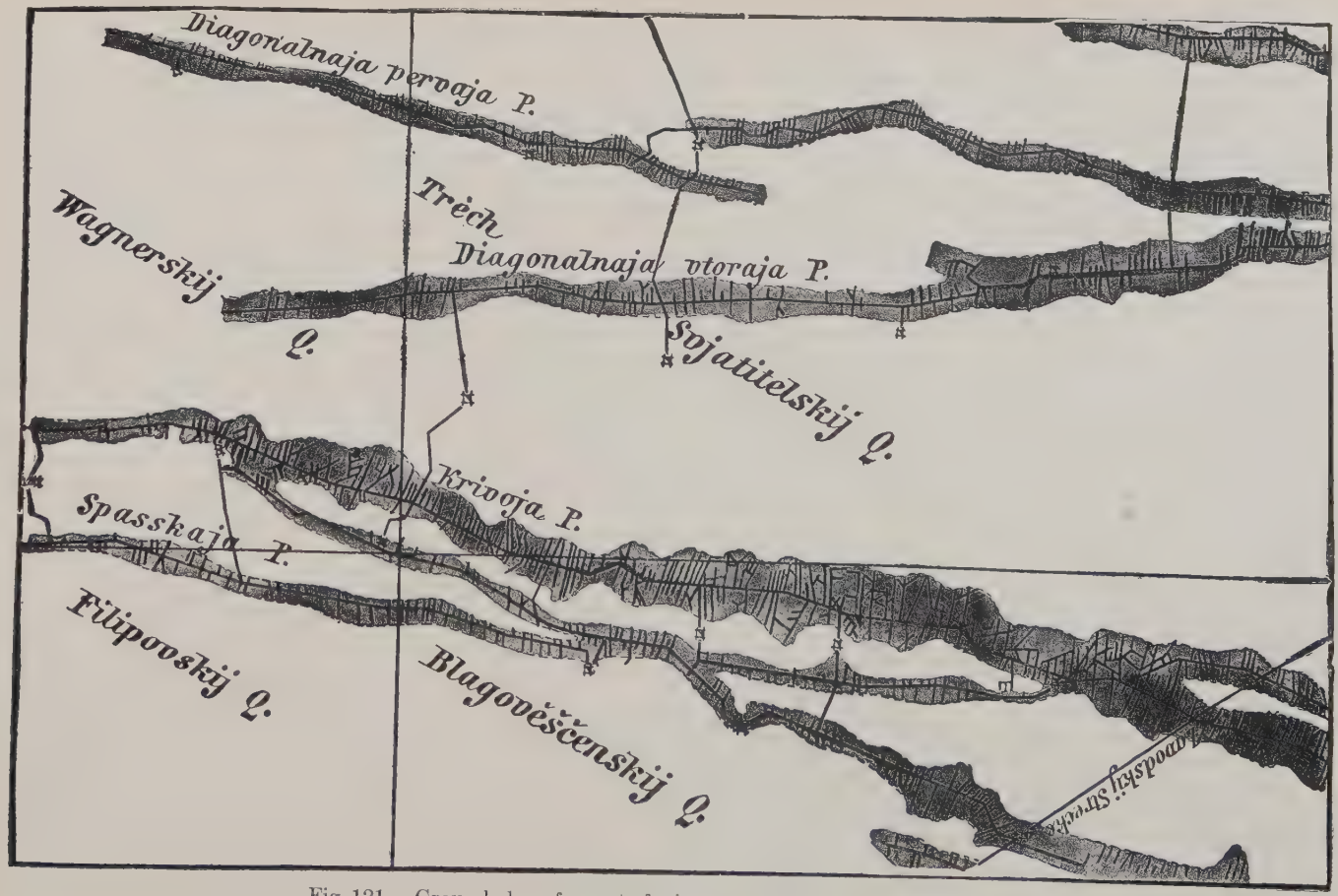


Fig. 121.—Ground plan of a part of mine area of Berezovsk. (F. Posepny.)

Carboniferous formation, for example, those occurring at Zwickau, which often carry zinc-blende and galena, are undoubtedly a result of contraction due to drying.

2. *Dilation Fissures.*

The best examples of these are the numerous fissures and slip planes which are so often found traversing stocks of serpentine. In such cases the cause of the increase in volume was the absorption of water in the serpentinization of the olivine rock. Such fissures have often received deposits of garnierite and other secondary iron and nickel ores, as in New Caledonia and at Frankenstein in Silesia.

β. Exokinetic Fissures.

I. *Fissures of Collapse and of Expansion.*

Collapse fissures (Einsturz spalten) are due to the caving in of the strata overlying a cavity formed by the leaching out of rock salt, gypsum or limestone. Instances of mineral deposits capable of such interpretation are not known. In a broader sense, this class of fissures includes those in great blocks of the earth's crust dropped down by the removal of great masses of material by volcanic eruptions, a feature not infrequently found on the concave side of mountain ranges. Certain ore-bearing lodes found in the eruptive districts of the Carpathian arch may be of this origin.

Expansion (tension) fissures are formed in beds overlying olivine rocks, which swell up on serpentinization, or above anhydrite lenses, that alter into gypsum. This may be the origin of some garnierite stringers, which are said to continue from the serpentine into the country rock.

Expansion fissures are more common in stratified rocks forced up into great arches by lateral pressure. The vein system of a mineralized tract may be explained in this way, as for example, that of Freiberg, which, as a whole, is situated over the summit of a great dome of gneiss. The fissures produced by folding may be summarized in a very general way, as follows:

II. *Fissures Due to Folding.*

Fissures develop, especially in the more brittle strata of a rock series, when the rocks are pressed together into folds, anticlines and synclines. Thus this class of fissures, like the folding itself, is due to the progressive cooling and contraction of the deeper zones of the earth's crust. They may be subdivided into *strike, intersecting* (at acute angles) and *cross* fissures,

according as their course conforms to, 1st, the strike of the folded beds; 2d, crosses the beds at an acute angle; or, 3d, crosses the fold at a right angle. It is probable that many mineral veins owe their origin to such rock flexures.

Strike fissures are almost always faults, generally overthrust faults. A. von Groddeck[1] mentions mineral veins in the Rhenish schists as examples of strike faults along folds. Such fissures are certainly not so frequent among veins as those crossing the folds at either an acute angle or a right angle.

The formation of these fissures is the result of an unequal distribution of pressure during the folding process. The intensity of a thrust acting vertically or obliquely against a fold may undergo a uniform diminution at slight intervals; for example, when an unusually resistant rock is

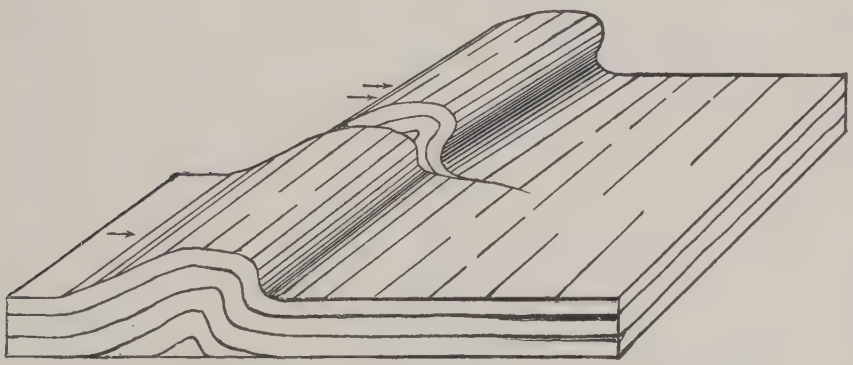


Fig. 122.—Model exhibiting the origin of fissures across folds.

encountered, or when pre-existing folds and fissures effect a deviation. In such cases a fissure forms between the more compressed and less compressed areas, as may be observed by an examination of the sketch-plan shown above (Fig. 122).

Foliation fissures are also produced by folding. If a pile of paper sheets be pressed together from the sides, some sheets will spread over each other; in the same way the layers of schistose rocks when pressed will fold up. The cavities thus formed have the shape of flat lenses, are generally curved irregularly, and may be filled with quartz containing ores, especially auriferous pyrite. Such *foliation fissures* are common among the gold-bearing quartz veins of the crystalline schists of the Appalachian region and Nova Scotia.

[1] 'Lagerstätten der Erze,' 1879, p. 316.

This class includes also the remarkable saddle lodes of Australia, described in detail previously.

III. *Compression Fissures.*

Some rock masses are unable to form folds when subjected to pressure. The hard and brittle eruptive rocks especially are not able to yield by folding, and in consequence are crushed and split. The cracks thus formed are appropriately called fissures of compression.

Our conception of this process is largely based on the beautiful experiments of A. Daubrée.[1]

In these experiments, cubes of brittle rocks are by simple pressure broken

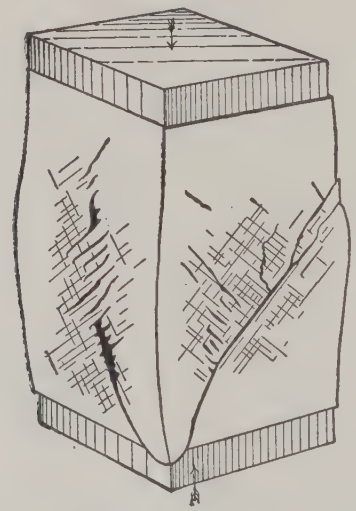


Fig. 123.—Artificial compression fissures in a prism. (A. Daubrée.)

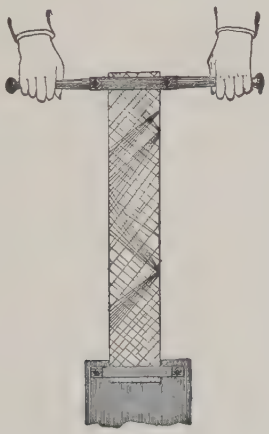
into irregular prismatic pieces arranged at right angles to the plane of pressure. In this case the direction of the fissure is parallel to the direction of pressure. In nature, however, the masses subjected to pressure are more or less plastic. Daubrée endeavored to approximate this condition in his experiments by using prisms consisting of a mixture of gypsum, wax and resin. The result was the formation of principal fissures, oblique (45°) to the direction of pressure, along which movement had taken place. These cracks were accompanied by a great number of lesser fissures on each side and running either parallel or at right angles to the main fissure

[1] A. Daubrée: 'Études Synthetiques de Geologie Experimentale,' 1879, p. 235.

(see Fig. 123). This cluster of fissures resembles in miniature the network of veins seen at Freiberg or that of the Cornwall tin district. As the mineral districts just named show clear evidences of lateral pressure, it is apparent that the plan of the veins of such an area is very properly comparable with the fissures on the surface of Daubrée's prisms.

Daubrée also experimented with artificial models made of alternate layers of different materials, the whole subjected to a pressure acting parallel to the stratification. In this way he obtained fissures running obliquely to the direction of pressure, accompanied by displacements when there was a chance for lateral displacement. The formation of fissures in this experiment was always preceded by a folding of the layers.

These experiments proved that the forces producing systems of parallel



g. 124.—Formation of regular fissure systems through torsion. (A. Daubrée.)

fissures, whether mere fissures of disruption or of displacement, did not necessarily act in the direction of the fissures. The direction of the force can only be inferred from the arrangement of all the fissure systems of a region. In the case of a system of paired fissures the diagonal seems to usually indicate the true direction. It is assumed, of course, that all the fissures taken into consideration are approximately simultaneous in origin, which, of course, is only in part true of the fissures at Freiberg and in Cornwall.

It also appears that a fissure and a displacement along this fissure may be produced by one and the same force.

Other experiments convinced A. Daubrée that under certain circumstances a torsion of a part of the solid crust of the earth would lead to a develop-

ment of perfectly regular fissure systems, especially for blocks of horizontal strata, such as plateaux and block mountains formed of level beds. By means of a wrench (Fig. 124) Daubrée twisted a rectangular plate of mirror glass on which a coating of paper had been glued. He obtained two systems of cracks running obliquely to the plane of torsion, one crack being often terminated against another. A consideration of the combined effect of the two forces, lateral thrust and gravity, shows that such torsional stresses and resulting fissures must often occur in nature. The fact that many of the cracks formed in the glass terminate one against the other is noteworthy, as it shows that a fissure dislocating another need not necessarily be younger than the dislocated fissure. It is only by a careful study of the fissure filling that the relative ages of the fissures can be determined.

These experiments of A. Daubrée have been repeated by G. F. Becker,[1] and the importance of their application to the theory of vein formation has been confirmed. The slickensides frequently found on fissure surfaces, even in veins with no apparent faulting, and the spiral bending and twisting of many vein walls, indicate that the fissures originate through torsion. Daubrée also, it may be observed, noted the spiral form of the cracks made in his glass plate.

Fissure systems still more closely resembling those in nature are obtained when provision is made for the asymmetrical and one-sided distribution of pressure and resistance in place of the symmetrical arrangement of Daubrée's experiment.

Lossen[2] ascertained this by accident. Cracks were formed in a pane of glass by the sudden opening out of a window sash caught below. These were mostly diagonal fractures, dipping in part in different directions, together with other curved and transverse cracks. The entire group of fissures bore a striking similarity to parts of the lode system of the upper Harz. Another variety of displacement that is manifestly a consequence of torsion forms the faults with opposing throw, failles a charnière (hinge faults), as they are graphically called by the French and Belgian miners. In this case each part of the faulted block has been elevated at one end of the fissure and depressed at the other end, while in the middle there is a neutral center or point of revolution (Fig. 125).

That the formation of fissures depends not only on the arrangement of the forces, but also to a certain degree on the greater or less brittleness and toughness of the country rock is manifest from the conditions already described (page 119).

[1] G. F. Becker: 'Torsional Theory of Joints,' *Trans.* Amer. Inst. Min. Eng., 1894, Vol. XXIV, p. 130.

[2] K. A. Lossen: 'Ueber ein durch Zufall in einer Fensterscheibe enst.,'etc. *Jahrb.* d. k. preuss Geol. Landesanst, 1886, p. 336.

(k) Time Required for Fissure Formation.

Well authenticated instances are known of the formation of vast fissures by a single shock during a violent earthquake. Thus according to B. Koto[1] a fault fissure was formed during a destructive earthquake in central Japan on October 20, 1891. The fissure showed both vertical and lateral shifting of the walls, and extended in a straight line across mountains and valleys for a distance of 64 k. (38.4 miles). At Midori the throw was 6 m. (19.6 ft.) and the horizontal shifting 1 m. to 4 m. (3.3 ft. to 13.1 ft.). This fissure did not gap. On the other hand, great open fissures were caused by the great earthquake in Calabria in 1783 at Monte Sant' Angelo.

Mining operations have exposed open cavities in true vein fissures in the Freiberg mines, as in the Churprinze mine, where druses were often encountered that were so large that a man might crawl into them.

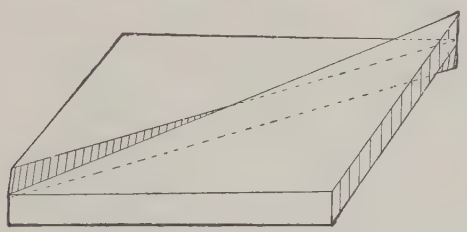


Fig. 125.—Model of a hinge fault.

Very broad veins are, however, not necessarily due to the filling of wide and open fissures. Observations upon veins show that, on the contrary, most large veins are due to an oft-repeated reopening of the fissures, so that only a small fissure space need remain open at a time. This successive fracturing has formed fissures not always exactly parallel to their predecessors, and not infrequently traversing them obliquely, as is proved by the frequent diagonal stringers of later age found in lodes. As an example, we may cite a rich silver quartz vein, the Traugott Spat, near Freiberg. This vein shows many irregular stringers of secondary quartz and ruby silver, cutting an older vein filling, consisting essentially of argentiferous blende, with some pyrite (Fig. 126). These younger quartz stringers are plainly distinguishable from the old vein filling on the selvage wall, whose characteristic comb structure proves it to have been formed before the blende mass.

The younger fissures will sometimes follow the wall or selvage of the old vein for a long distance and then cut directly across the vein. This condition results in the formation of cross stringers, which pass immediately into parallel stringers along the wall. The specimen shown in Fig. 127 is

[1] 'On the Cause of the Great Earthquake in Central Japan, 1891,' Tokio, 1893.

taken from the Komet Stehende on the Himmelsfürst mine, near Freiberg. (Fig. 127.) The cross vein of the specimen consists of white calc-spar, with some pyrite, while the mass of the vein cut by it consists of reddish rhodochrosite with zinc-blende and pyrite.

Fig. 126.—View of the vein of the Traugott Spat (rich quartz formation). From nature; an example of a vein reopened many times in succession. (Composite vein.)

gn, decomposed gneiss; q, vein filling, consisting essentially of quartz; e, ore, mainly argentiferous blende, with some copper pyrite, as well as galena.

Clay selvages and false walls are often formed by movements taking place after the vein has been formed, and, as shown by Emmons,[1] they may lead the miner astray or prevent his discovering pay shoots. Drifts are often

[1] S. F. Emmons: 'Origin of Fissure Veins,' *Proc.* Colo. Sci. Soc., 1887, p. 200.

run along such planes of easy breaking, because they are thought to be the true wall of the entire lode, and because, moreover, it greatly facilitates the loosening of rock and ore. In such a case when a cross drift is finally run through the clayey or altered and rotten country rock, inside the false wall, a second layer or stringer may be encountered lying parallel to the one hitherto worked, and which is perhaps much richer. The selvage apparently defining the wall is merely a plane due to reopening of the lode.

(1) The Filling of Vein Fissures.

As already pointed out, it is seldom that vein fissures are filled with ore alone. Most often the vein filling is made up of ore and gangue (*i. e.*, non-

Fig. 127.—View of the Komet Stehende (Carbonspathic lead formation) with a cross stringer.

gn, gneiss; m, manganspar; b, brown spar; p, pyrite, blende and galena.

metallic minerals), together with fragments of the country rock showing various conditions of comminution, trituration and decomposition. In compound lodes this filling is the rule, and in many cases these masses of altered country or veinstuff form the main mass of the vein filling.

The most widely distributed gangue minerals are quartz and the carbonates (calcspar, brownspar, dolomite, magnesite, manganese-spar, mangan-calcspar) also barite and fluorspar. The less common constituents are zeolites, gypsum, orthoclase, lithia-mica and chlorite. It is usually assumed that certain particular species of non-metallic minerals do not occur in veins, and the presence of these minerals in an ore deposit is considered as a proof that the deposit is not a mineral vein. Such assumptions must, however, be used with caution, for it has been repeatedly found that various minerals supposedly absent in veins have subsequently been found in them. This is true, for example, of actinolite, which, according to W. Möricke,[1] occurs together with tremolite, quartz and calcspar as the matrix of the gold-bearing copper veins of La Higuera in Chile, and, according to W. Lindgren,[2] in the auriferous copper veins of Rossland, in British Columbia. Garnet, which was formerly supposed to be foreign to lodes, has now been shown to exist in veinlike orebodies.[3] G. F. Becker mentioned it many years ago as a constituent of certain gold-quartz veins of the Appalachians.[4]

(m) Structure of the Vein Filling.

It is evident that the development of one or more of the minerals of a vein in a peculiar form, as, for example, the coarsely foliated development of calcspar, the sheaves of fibrous pyrolusite, etc., will influence the structure of the lode as a whole, particularly if one of the minerals predominates. As a rule, however, several gangue and ore minerals are present in the vein filling, and the structure of the aggregate is the result of the mixture and intergrowth of all these minerals. The intergrowth and relation of the vein minerals to each other (paragenesis) has been studied very closely megascopically, *i. e.*, so far as recognizable with the naked eye, ever since the time of G. A. von Weissenbach.[5] Very little, however, is as yet known of the microscopic structure of ores, although the result of such studies may throw much light on the question of ore genesis and deposition, and offers a wide field for future investigation. Up to the present time such studies have been confined almost entirely to the ores of gold-quartz lodes. This subject will be referred to later.

While veins show a great variety of structures, the following types of vein structures may be distinguished:

[1] W. Möricke: 'Die Gold, Silber und Kupfererzlagerstätten in Chile,' Freiberg, 1897, p. 27.

[2] *Trans.* Am. Inst. Min. Eng., February, 1900, p. 33.

[3] R. Beck: 'Beiträge zur Kenntniss von Brokenhill,' *Zeit. f. Prak. Geol.*, 1899, pp. 65-71.

[4] 16th *Ann. Rep.* United States Geol. Survey, Vol. III, p. 274.

[5] G. A. von Weissenbach: 'Abbildungen merkwürdiger Gangverhältnisse aus dem sächs. Erzgebirge,' Leipzig, 1836, p. 27.

1. *Massive Filling.*

A massive filling is especially common in 'simple' veins, and the gangue and ore minerals usually show a compact massive development. Many gold quartz veins are of this type, the vein consisting of a uniform and compact mass of quartz containing disseminated grains of gold-bearing pyrite and particles of free gold (disseminated vein structure). Many pyrite-blende-lead veins show this structure, an older fissure being filled with com-

Fig. 128.—View of the Rudolf Stehende (pyritous lead ore formation) with dominant massive structure. (From nature.)
gr, decomposed gray gneiss; q, quartz; b, argentiferous galena; s, pyrite.

pact ore. Fig. 128 represents the Rudolf Stehende on the Himmelsfahrt mine near Freiberg, in which the vein is mainly compact galena.

Examples of a purely massive structure are seen in the small lodes of compact bornite ore encased in gneiss at Hvidesöe (Hvideseid), Norway.

2. *Banded or Crusted Filling.*

This filling in which the different constituents are arranged in more or less sharply defined layers or crusts is a common feature of veins. It is

wholly unlike the structure prevailing in mineralized igneous dikes, and is readily distinguished from the stratified structure of sedimentary deposits.

When the crusts are very thin they commonly occur in great number, as, for example, in many of the lead-barite veins in the Erzgebirge. A typical example is shown in Fig. 129 representing a specimen from the Friedrich vein of Memmendorf in the Erzgebirge. The delicate crusts consist respectively of dense barite, fluorspar, zinc-blende and galena.

When the minerals forming a crust are crystalline and the crystals are elongated and arranged at right angles to the layer so that the ends of the

Fig. 129.—The Friedrich Spat (barytic lead ore formation) with definite layer structure. (From nature.)

crystals project into the next following crust or into a free druse space, it is known as 'comb structure,' a variety of crustification confined to mineral lodes. This structure is shown by the primary quartz layers of the Traugott vein in Fig. 126, and it is common in veins of the rich silver quartz class. The ore breccia of the Himmelsfürst mine (Fig. 133) shows this structure, quartz crystals projecting into a dark band of blende.

Occasionally there is a regular and symmetrical development of the crusted structure with a regular succession of mineralogically different

crusts, counting from the vein wall to its middle, the succession following a definite order. This symmetric crust-structure is very common in lead-barite veins of the Freiberg district, and is also observable in many tin veins of the Erzgebirge. The symmetric succession may be repeated several times, as shown in the filling of the Drei Prinzen vein of the Churprinz (Fig. 130). In this we may distinguish the following crystalline layers stated in order from the selvages toward the middle:

Fig. 130.—The Drei Prinzen Spat (a barytic lead vein) with symmetric crust structure. (G. A. von Weissenbach.)

(a) Brown blende; (b) white quartz; (c) asparagus green fluorspar; (d) an exceedingly delicate band of brown blende; (e) dirty, flesh-red, curved, scaly barite; (f) a narrow band of radiated pyrite; (g) barite like e; (h) fluorspar like c; (i) band of marcasite like f; (k) white calcspar; (l) light wine-yellow calcspar occasionally forming small druses in the middle. The lode traverses gneiss.

The number of layers and of the different minerals and the regularity and symmetry of this specimen are very exceptional. A crust may form at first

only on one wall of a lode and afterward simultaneously on both or *vice versa*. Such alteration may even be caused by chemical reaction of pre-existing crusts on the circulating solutions. If a vein is fractured and the old fissure reopened by a crack that does not exactly follow the middle of the vein, the crusts subsequently formed are not symmetrically disposed with those of earlier origin. An example of this is shown in Fig. 131

Fig. 131.—View of the Frischglück Stehende (rich quartz formation). (G. A. von Weissenbach.)

(after G. A. von Weissenbach), representing the filling of the Frischglück vein at Klein-Voigtsberg.

In this illustration we see that, progressing successively from right to left, new openings and new double crusts have been formed, which could not conform to those of the oldest part of the lode. On the other hand, in lodes formed by rising water and at great depths below the surface, it is inconceivable that such unsymmetrical deposition could be dependent on the inclination of the lode unless it is assumed that the water did not fill

the fissure, but followed its foot-wall. Such vein fissures must have been completely filled with water, and it is only in the zone above the water level that such partial and unilateral fissure filling is conceivable, as pointed out by F. Posepny.[1]

That the form of the crusts is dependent on the form of the cavity walls is best exhibited by the crusts which rest directly upon the country rock. We may distinguish: (a) flat crustified vein filling; (b) concentric crusted vein filling. The former predominates in vein fissures with approximately rectilinear walls. The latter is found on projections of the fissure walls, and

Fig. 132.—Concentric crusts of the Drei Prinzen Spat (a baritic lead vein). (From nature.)

is even more beautifully exhibited by the coatings about included fragments of country rock, or of fractured older vein filling of the fissure. Finally, this structure may be developed by the filling of the spherical spaces left in the partly filled fissure, as is very often the case with ore deposits filling cavities in limestones and dolomites.

A fine example of concentric crusted structure along the selvage of a vein is shown in Fig. 132, representing a specimen from the Drei Prinzen Spat of the Churprinz mine near Freiberg.

In this specimen masses of galena are surrounded by exceedingly thin shells or layers of barite and crusts of fluorspar. The kidney-shaped layers

[1] F. Posepny: 'Genesis,' p. 78.

of barite superimposed a hundredfold in some Freiberg lodes were justly compared by C. F. Naumann with the formation of travertine or hot spring sinters.

The gradual encrustation of rock fragments originally lying loose within the vein fissure may sometimes be traced step by step. At first there is only a scanty coating of minerals, so that the fragments are not as yet firmly cemented to each other. Such is the condition of the very imperfect quartz breccias of some tin ore lodes of Zinnwald, cemented by a recent deposit of quartz, scheelite and fluorspar; of the mica schist fragments loosely cemented by barite in the Eduard Spat of the Himmelsfürst mine. More

Fig. 133.—Breccia structure in the Lade des Bundes Flache at Himmelsfürst near Freiberg. (From nature.)

commonly there is complete cementation of brecciated material, but without crustification. Such simple lode breccias are rather common in all large lode areas, as at Freiberg in the upper Harz, and at Pribram. The cement, of course, varies with the character of the lode. Thus, for example, at Pribram dark schist fragments are often found cemented by zinc-blende, brown spar and quartz. In other cases, the breccia consists of fragments of an older lode filling and not of country rock. This is well shown in the ore from the Lade des Bundes Flache (drift No. 8, 1884) shown in Fig. 133.

In this case sharply angular platy fragments of decomposed gneiss and of an older crustified vein filling of quartz, blende and galena are imbedded

in a drusy cement of brownspar. The brittle galena is completely comminuted.

If the different ore and gangue minerals form crusts about the fragments, *ring* ores or *cockade* ores are formed. In the Freiberg area such "Spharengesteine" (spherical rocks), as they used to be called, are well known in the Peter Stehende of the Alte Hoffnung Gottes mine and in the Helmrich Spat of the Gesegnete Bergmanns Hoffnung mine. But nowhere are they so magnificently developed as in the upper Harz, especially in the "Ring und Silberschnur," near Zellerfeld. The specimen represented in Fig. 134 was taken from this mine.

Fig. 134.—Ring ore from the "Ring und Silberschnur" mine in the Harz. (From nature.)

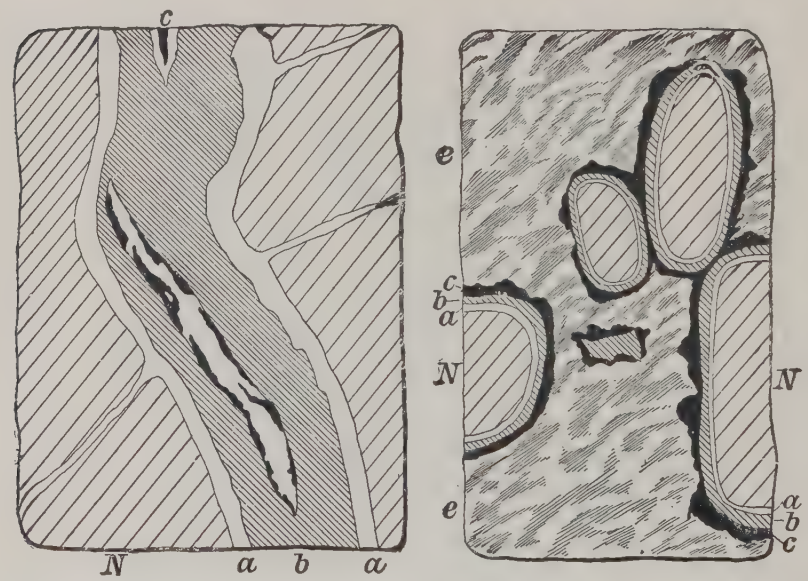
The specimen shows fragments of quartzitic sandstone and dark colored slate surrounded by galena, zinc-blende and quartz. If the succession of the different crusts of the ring ores be examined, it is found that the layers show the same order of succession as those on the walls of the stringers and veins. This is seen at a glance in a comparison of Fig. 135 and 136 (after A. von Groddeck).[1]

Sometimes the first crust formed on the fragments is so sharply defined from the later ones that it appears to constitute the true nucleus or rock

[1] A. von Groddeck: 'Erzlagerstätten,' p. 64.

fragment. Thus, according to Phillips-Louis,[1] the main vein of Huelgoet in Brittany consists of what appear to be quartz pebbles cemented by blende, pyrite, quartz and lead glance. In reality these pebbles are fragments of slate surrounded by concentric shells of quartz resembling fibrous chalcedony. In fact, this radial structure is very common in the individual crusts formed about rock fragments, especially the quartz crusts, forming the so-called cockade ores. In such cases the crust may resemble stellate quartz.

The encrusted balls of such ring ores are sometimes isolated, and there is no contact between the original rock fragments, and hence A. von Weis-



Figs. 135 and 136.—Specimens of vein filling from the Bergmannstrost mine. (A. von Groddeck.)
N, country rock; a, quartz; b, lead glance; c, zinc-blende; e, calcspar.

senbach[2] and Reich have inferred that fragments originally in contact were forced apart by the crystallizing force of the minerals subsequently segregated, just as fragments of the Alte Mann in the Sauberg, near Ehrenfriedersdrof, according to C. F. Reich, were driven apart by the crusts of freezing seepage water. While the process in itself is physically quite conceivable, it must be remembered that in some cases the only reason why

[1] 'Ore Deposits,' p. 88.
[2] G. A. von Weissenbach: 'Abbildungen merkw. Gangverhältnisse,' 1836, p. 22.
[3] F. Posepny: 'Genesis,' p. 89.

points of contact are not found is that the observers cannot compare a sufficient number of parallel sections.[1]

Ring ores are often of very recent formation, and there are even cases where their formation takes place before our eyes. Posepny mentions the quicksilver deposit of Sulphur Bank, California, where fragments of basalt, sandstone and slate are coated with concentric layers of cinnabar by the hot spring water. If the concentric crusts occur as coatings on the walls of cavities, their form depends on the shape of the little cavity. This is also well shown in the cross-sections of agate amygdaloids. The crusts may in such cases either line all parts of the wall uniformly, or the layers may only be found at the bottom, or finally the two cases may be combined. Very good examples of such cavity fillings are found in the zinc lead deposits of Raibl (see further on), where fibrous blend is found to be made up of thin layers of dense zinc-blende and galena.

Druses occur in lodes as well as in chambers. These druses or vugs are characterized by an inner coat or crust studded with crystals projecting into an open space. They are not always the residual spaces of an imperfectly filled fissure, but may be formed by a secondary leaching out of older crusts or by the solution of fragments of the country rock. Such crystal formations are even possible in stratified deposits; for example, druses formed by the leaching out of plates of anhydrite and the subsequent deposition of calcspar in gypsum deposits. As a rule, however, druses are characteristic of cavity filling.

These vugs are sometimes quite large. In the Freiberg lodes they are sometimes large enough to admit a man's head. They are usually situated in the middle of the lode (see p. 173).

The minerals forming the druse walls show the successive deposition of the various ore and gangue minerals even better than the material filling the body of the vein, the crusts sometimes showing several generations of each ore. One should, however, be cautious in drawing conclusions from such observations, since the minerals found in these vugs are often formed at a much later time than those which constitute the real vein filling. In fact, this deposition in vugs is in some veins known to be taking place at the present day. Undoubtedly, in many instances, the deposition of druse minerals took place under physical and chemical conditions different from those prevailing when the true vein filling was formed, and at a later time, when this section of vein had been raised above the level of ground water, as a result of extensive superficial denudation of the country.

While we have every reason to believe that the open vein fissures were, at some depth below ground-water level, entirely filled with mineral solutions,

[1] F. Posepny: 'Genesis,' p. 88.

this may not always have been the case with the residual open parts of those fissures left unfilled until the stage of druse formation. That this is true is shown by the not infrequent occurrence of later minerals deposited on the upper side of the large crystals of vugs and druses. This is common at Freiberg; thus the large quartz crystals of the Drei Bruder vein at Obergruna are coated on one side only with brown-spar and other car-

Fig. 137.—Group of quartz crystals encrusted on one side with brown spar. (From nature.)

bonates (see Fig. 137); similarly the quartz crystals of the Selig Trost Flache lode of Himmelfahrt mine near Freiberg are coated with ankerite and pyrite on one side only. These conditions show that descending solutions seeped through the druse spaces, so that only the downward facing surfaces received new secretions, as may be seen with ice crusts along the eaves of houses in the winter.

The new mineral secretions formed in open cavities (*i. e.,* containing only gases or air) produce stalactites at points where the amount of water is sufficient to overcome adhesion and drop downward by gravity. Such stalactitic deposits are most common in ore deposits forming irregular filling of cavities[1]; particularly in zinc-lead deposits in dolomites and limestones. At Raibl stalactitic tubes of galena occur that are as much as ten

[1] J. de la Fontaine: 'Beitrag zu Kentniss Stalak. Vorkommnisse u. deren Genese,' Berne, 1882.

centimeters in length; they consist of a number of delicate, concentric crusts of this mineral, combined sometimes with crusts of zinc-blende and pyrite. The center is often a cavity through which one could blow. These stalactites of galena were, it is true, no longer pendent from the cavity roof, but had fallen and been embodied in a later deposit of dolomite spar. Since the succession of the several crusts is not the same in all, it is probable that they fell at different times.

The fibrous blende of the zinc deposits of Raibl is also in part a stalactite formation, occurring as hemispherical stalactites and reniform and botryoided masses formed on the cavity roof. It consists of very fine concentric scales of blende and galena, as well as of pyrite. This fibrous blende is most beautifully developed in the Schmalgraf mine near Moresnet. Fig. 138 shows a cross-section of fibrous blende from that locality.

At Wiesloch in Baden long stalactites of calamine and galena were formerly found which resembled in form and occurrence the calcspar stalactites of caves. Similar examples occur in the calamine mine of Catavera in Spain. The Freiberg collection contains a specimen from that locality that is a fine, slender, snow-white zincspar stalactite 0.25 meters in length, not counting the missing point.

Stalactite formations are also known to occur in the vugs of veins. They are most common in deposits of manganese and iron, especially psilomelane and limonite. As examples we may mention the stalactite groups of psilomelane in the spathic iron ore lode of the Luise mine at Horhausen (see Fig. 139), and those from the iron ore lodes of the Schwarzenberg region in the Erzgebirge. Stalactites of brown hematite are found in the veins of the Siegen country and in those of Aue in the Erzebirge. Stalactites of pyrite were found at Freiberg in the Johannes vein of Himmelsfürst, and some of pyrite in the Lade des Bundes Flache of the same locality. We ourselves possess a group of marcasite stalactites collected by H. Muller from the workings in the Drei Prinzen vein of the Churprinz mine near Freiberg (above the sixth drift of the Friedrich gallery on the west, about 230 meters below the surface). As lode fissures at such a depth are far below ground-water level, these stalactites could only have been formed within an empty or gas-filled cavity, which renders their explanation very difficult.

The most remarkable occurrence of this kind is, without doubt, the stalactites described by F. Posepny[1] from the Matyas Kiraly mine at Verespatak in Hungary (illustrated in Fig. 140). They are completely studded externally with small quartz crystals, while internal layers of calcspar alternate with layers of rhodonite; in the middle line angular gold wires run

[1] F. Posepny· 'Genesis,' p. 95.

down which sometimes project at the lower gently rounded ends of these stalactites.

Mention must also be made here of the stalactites of crystalline quartz (or chalcedony) 7 centimeters long, from a druse cavity in the cobalt ore lode of Scheneeberg, described by H. Muller.[1]

Stalactites of ore minerals, as well as unilaterally encrusted crystals, must be regarded as records of a descending movement of solutions along vein fissures, as suggested by A. Schmidt[2] for the stalactites of Wiesloch.

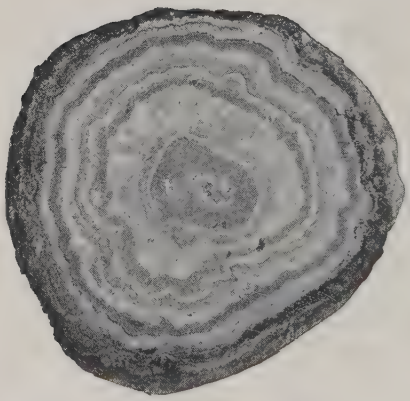


Fig. 138.—Cross-section through a stalactite of fibrous blende from Moresnet. (From nature, two-thirds natural size.)

b, lead glance; p, pyrite; z, zinc-blende; outer crust limonite.

Fig. 139.—Psilomelane stalactites from the Luise mine near Horhausen. (From nature.)

Of course, one may adopt the alternative explanation suggested by F. Posepny,[3] namely, that, with sufficient pressure, uprising solutions may also be pressed through the roof of cavities when the floor and side walls are not permeable. This mode of origin, however, is undoubtedly of very rare occurrence. The above mentioned occurrence in the Churprinz may be an instance of it.

[1] H. Müller: 'Ueber eine merkwürdige Druse auf einem Schneeberger Kobaltgänge.' *Z. d. d. g. G.*, 1850, p. 14.

[2] A. Schmidt: 'Die Zinkerzlagerstätten von Wiesloch in Baden,' 1881, p. 94.

[3] F. Posepny: 'Genesis,' p. 93.

In conclusion we may mention, in discussing lode structures, that in some lodes soft clayey masses of crushed material contain nodular concretions of ores and of gangue minerals. Examples are seen in the nodules of native copper in a vein of the Vesuvio mine near Salinas, east of Mejillones in Chile; of zinc-blende, in the Malhada mine near Albergia Velha in Portugal; siliceous concretions in vein clay of the Gott mit Uns vein of the Himmelsfürst mine near Freiberg. Such formations could develop only in a medium whose particles could readily be driven asunder by the force of crystallization.

(n) Paragenetic Occurrence of Vein-Forming Minerals.

By paragenesis of minerals August Breithaupt[1] understood "the more or less definite manner of their association," at the same time "laying par-

Fig. 140.—Cross-section through a stalactite of Verespatak. (Posepny.)
g, gold; c, calcite; r, rhodonite; q, quartz; d, druse.

ticular stress on the relative age of the materials where a succession may be recognized."

Examples of such associations, given by Breithaupt, may be mentioned here. Copper pyrite will always be found where bismuthinite is present. In like manner pyrrhotite and copper pyrite, bornite, chalcopyrite and pyrite are always found associated. There is an especially intimate connection, as a rule, between fluorspar, topaz, molybdenite, wolframite and tinstone; of the common manganese and iron ores; galena and zinc-blende; cobalt and bismuth ores. Such associations have always been of practical importance to the miner and prospector in unexplored regions. The finding of certain minerals, either of ore or gangue, warns the prospector

[1] 'Die Paragenesis der Mineralien,' Freiberg, 1849.

to keep a keen lookout for the associated valuable mineral. If in a quartz vein you find pyrite, arsenopyrite and antimonite, the search for gold in the outcrop, as a rule, will not be in vain.

Quite as important as this association of the minerals is the manner of their intergrowth or succession, and the investigation of these features may throw much light on the genesis of the ore deposit in question. The definite succession of the various chemical crusts, the superposition of the druse minerals in a definite order betrays, in many cases, a progressive change in the chemical constitution of the solutions that circulated in the fissure, and possibly a change of the conditions of pressure and heat in the mineral springs supplying the material for the vein. It is true that the application of these hints to particular cases is as yet impossible. The recent important work of J. Vater and others on the influence of the accompanying solutions is merely the beginning of the exact studies which must be made before any definite conclusions can be reached on this subject. Sometimes the succession of minerals appears quite capricious. Thus, as mentioned by A. Breithaupt, in the beautiful druses of the barytic lead veins, the younger calcspar always rests on barite, never on pyrite. "It occasionally arches away over the pyrite as if it were trying to keep out of its way." In like manner, in the Bescheert Glück mine near Freiberg, the later formed ruby silver of the druses occurs only on white silver ore, not on galena.

A definite succession of minerals recurs with special regularity in the tin lodes of Saxony. The quartz and lithia mica form the basal layer, followed by topaz, cassiterite and wolframite, and finally by fluorspar and scheelite, together with uranium-mica (chalcolite).

In many cases the succession of the minerals is inversely as their relative solubility. "In many fissures and cavities the walls are covered with quartz druses followed by crusts of calcspar. The quartz being far less soluble in water, was of necessity deposited first." (Tschermak[1].)

Conclusions regarding the succession of minerals may often be drawn from the nature of pseudomorphism. The significance of this feature is very forcibly emphasized by C. F. Naumann.[2] "These residual monuments of former mineral bodies, now completely or almost completely vanished, give us a deep insight into the various processes of formation and reformation, destruction and annihilation that takes place successively in the course of time within the lode spaces, and which prove not only a very long duration of the lode forming process, but also a frequent change in conditions and a perplexing variation in the efficiency of each cause."

[1] G. Tschermak: 'Lehrbuch der Mineralogie,' 1894, p. 271.

[2] C. F. Naumann: 'Lehrbuch der Geognosie,' Leipzig, 1866, Vol. III, p. 575.

Sometimes almost all the mineral contents of a lode is affected by pseudomorphism. Thus the silver-cobalt lodes of Schneeberg originally had a gangue of calcspar and barite, which is at present almost always transformed into hornstone, common quartz, chalcedony and amethyst. In the silver-gold ore lodes of De Lamar,[1] Idaho, and the gold-silver veins of the Drumhummon mine, Montana, the original calcite and barite of the gangue has been replaced by quartz, and at the former the country rock and rhyolite have been partly silicified. This replacement of calcite by quartz is now actually taking place in the veins forming at Boulder Hot Spring, Montana.[2]

Neither the work of A. Breithaupt nor the earlier work of W. J. Henwood[3] on the mineral succession observed in definite vein types has led to the discovery of any laws of general application, and the same is true of the more recent studies of F. Sandberger[4] and others. At most the conclusions apply to limited areas only. The influence of local conditions, the number of substances dissolved, and consequently the multitude of consequent reactions of the substances among themselves and with the constituents of the country rock, make the phenomena exceedingly complicated.

(o) Vein Formations and Vein Types.

All the distinctive features of a vein, those of paragenesis and mineral succession, geological conditions, prevailing structure, the nature of its country rock, its age, etc., give to it a distinctive character and a particular type will always recur where lodes have been formed under similar conditions. This fact has been used by different authors in various attempts to group the confusing multitude of mineral veins into a number of types, a group to which additions are constantly made. Various attempts have been made to classify veins according to their physiognomy, with the greatest possible scientific precision. G. A. Werner, and after him S. A. W. von Herder, J. C. Freieslehen and A. Breithaupt, distinguished 'formations'; A. von Groddeck and J. H. L. Vogt distinguished 'types.' These attempts, however, have been but partly successful, owing to the difficulty of assignment resulting from the transitional or composite features in the physiognomy of the veins. Moreover, the same vein may change its character in strike or dip. In studying such changes in dip a rigorous discrimination must, of course, be made between those differences that existed

[1] W. Lindgren: 20th *Ann. Rep.* United States Geol. Survey, part III, 1900, p. 164

[2] W. H. Weed: 22d *Ann. Rep.* United States Geol. Survey, 1902.

[3] *Trans.* Roy. Geol. Soc., Cornwall, Vol. V, 1843, p. 214.

[4] 'Untersuchungen uber Erzgänge,' Wiesbaden, 1882, I, p. 96.

from the beginning and those that were subsequently added, that is to say, between the primary and the secondary differences in the physiognomy of the lode according to depth, as will be discussed in detail further on. It may also happen that two characteristic mineral associations may occur in one and the same fissure, but in separate groups, as, for example, in some lodes of the Himmelsfürst mine near Brand, where one stringer belongs to the pyritic-blendic lead type of deposit, while the other belongs to the spathic lead class; or in Tuscany, where the north part of the Boccheggiano vein is a typical quartzose copper ore, while at the south it must be classed as a pyrite-blende lead deposit.

In classifying a vein by its mineral contents the main point to remember is (as emphasized by A. Breithaupt) to base one's judgment not on one specimen or on a few specimens in a collection, but to determine the general character of the vein from the examination of very many samples belonging, if possible, to the most diverse parts of the vein, and, so far as may be done, uniting the data found in many separate lodes of an area into a general picture after inspection of the occurrence *in situ*. In old mining regions, as at Freiberg, in the Harz, in Cornwall, etc., where scientific observations have been made and recorded for a long time, the grouping of the various vein formations has, after many vicissitudes, at last been fixed in a scientifically satisfactory manner, after discarding the sub-classes formerly used.

The fundamental idea and definition of "lode formation" is due to G. A. Werner, who expressed himself on this point as follows:[1] "I give the name 'lode formation' to all lodes of one and the same origin, whether they occur close together in one region or far apart in different countries." Werner distinguished eleven mineral formations or 'niederlagen' for Saxony alone; Von Herder limited the number for the Freiberg area to five; Freiesleben by establishing subdivisions raised the number to fifty; Breithaupt took twenty for his standard, while von Groddeck established a great multitude of converging types which often can be distinguished only by emphasizing the local mode of occurrence, the nature of the country rock, etc.

A complete summary of the older literature on vein formations is found in the valuable treatise by G. A. von Weissenbach[2] 'on lode formations.'

In the following pages a summary is given of the most important mineral veins of the world. In this summary the arrangement followed is a modification of the one adopted by A. W. Stelzner for the collection of ores from the Freiberg deposits, a system which closely follows the old Freiberg classi-

[1] G. A. Werner: 'Neue theorie von der Entstehung der Gänge,' 1791, p. 5.
[2] Cotta's 'Gangstudien,' 1847. Vol. I, p. 1 *et seq.*

fication, which has met with acceptance by many students of ore deposits. The classification of gold deposits and some other details are innovations made by the author.

Following this summary of the leading features of each class and its subdivisions, a brief characterization of each group or formation will be given. This will be followed by a brief description of selected examples. For this purpose preference will be given to the deposits of producing mining regions, to those recently opened and to those deposits which even though no longer worked are world-famous and have been carefully and scientifically studied. In the brief descriptions given, it is impossible in some instances to treat certain types of veins separately and independent of their connection with the general geologic conditions of the mineral area, and it is therefore necessary in such cases to give, in a few lines, a geologic sketch of the whole region.

SUMMARY.

The Different Classes of Mineral Veins and Their Varieties.

A. Veins Consisting Mainly of Oxidic Ores.

I. *Veins of Iron and Manganese Ores.*

1. Veins of spathic iron ore (spathic iron ore formation).
2. Veins of red hematite (red hematite formation).
3. Veins of manganese ores (manganese ore formation).

II. *Tin Veins.*

4. Tin veins (tin ore deposits).

B. Deposits Characterized by Metallic Sulphides.

III. *Copper-Bearing Veins.*

5. Veins with copper ores in a gangue characteristic of tin deposits (tourmaline-bearing copper formation).

6. Quartz veins containing copper ores (quartzose copper formation).

7. Veins containing copper ores in a gangue of carbonates and quartz, together with barite and sometimes fluorspar as gangue (spathic copper formation).

8. Veins of native copper with carbonates and zeolite (zeolitic copper ore formation).

IV. *Silver-Lead Veins.*

9. Veins of predominant quartz with argentiferous galena, zinc-blende, pyrite and arsenopyrite (pyritic lead ore formation).

10. Veins of calcite and other carbonates with argentiferous galena, zinc-blende and rich-silver ores (spathic lead formation).

11. Veins of barite and fluorspar, with galena, zinc-blende and rich-silver ores (barytic lead formation).

V. *Veins Carrying Rich Silver Ores.*

12. Veins of quartz with rich-silver ores (silver-quartz formation).

13. Veins of calcspar with rich-silver ores (silver-calcspar formation).

14. Veins with both copper ores and rich-silver ores (rich silver-copper ore formation).

15. Veins with silver cobalt, nickel, bismuth, and uranium ores (rich silver-cobalt ore formation).

VI. *Gold Veins.*

16. Veins with predominant quartz gangue containing gold ores (gold quartz formation).

(a) Gold quartz veins with predominant pyrite (pyritic gold quartz formation).

(b) Gold quartz veins with copper ores (cupriferous gold quartz formation).

(c) Gold quartz veins with stibnite (antimonial gold quartz formation).

(d) Gold quartz veins with arsenopyrite (arsenical gold quartz formation).

(e) Gold quartz veins with cobalt ores (cobalt gold quartz formation).

17. Veins of quartz and carbonates with gold and silver ores (silver-gold ore formation).

18. Veins of quartz and fluorspar with gold ores (fluoritic gold formation).

VII. *Veins of Antimonial Ores.*

19. Veins of predominant quartz with antimony ores (antimonial formation).

VIII. *Veins of the Cobalt, Nickel and Bismuth Ores.*

20. Veins of nickel and cobalt ores in a carbonate gangue (carbonspar cobalt ore formation).

21. Veins of quartz with cobalt, nickel and bismuth ores (quartzose cobalt formation).

22. Veins of hydrated nickel-magnesia silicates (hydrosilicate nickel formation).

IX. *Lodes of Mercurial Ores.*

23. Quartz-calcite quicksilver formation.

B. DESCRIPTIONS OF VEINS OF EACH TYPE.

(-) Veins Consisting Mainly of Oxidic Ores.

(d) Iron and Manganese Veins.

1. *Veins of Spathic Iron Ore.*

The veins consist essentially of siderite with quartz or calcspar, and subordinate pyrite, copper pyrite, etc., and barite. The alteration of the upper part of the veins into brown hematite liberates the manganese originally present as carbonate, and this is frequently segregated in the form of pyrolusite, manganite, psilomelane and wad.

An important example of this type, now of but little economic importance, is the Stahlberg near Müsen, where a lode 12 to 27 meters thick has been worked since 1313.[1] The vein occurs in lower Devonian clay and graywacke slate. It is cut off to the southeast by a fault, while northwest it splits into three main branches, which also subdivide, and have been followed to a distance of 145 meters. It dips east 80°, and consists of almost pure, or but slightly quartzose, compact spathic iron ore, whose high manganese content renders it desirable for the manufacture of steel. There are but slight admixtures of copper pyrite, pyrite, gray copper and galena. The walls are not sharp, and the country rock is penetrated by fine stringers of spathic iron ore.

In 1901 the mines of this type in the Siegen country yielded 854,008 tons of iron ore. The Siegen I district produced 641,170 tons and the Siegen II district 212,838 tons.

[1] A. von Noggerath: 'Die Grube Stahlberg bei Müsen,' *Z.* f. d. B. H. u. S. im preuss. St., 1863, Vol. XI, p. 63. Th. Hundt, G Gerlach, F. Roth, and W. Schmidt: 'Beschreibung der Bergreviere Siegen I und II, Burbach und Müsen.' Bonn, 1887, p. 137.

Similar conditions prevail in the vein of spathic iron ore of the Luise mine, near Horhausen, described by Hilt,[1] as well as in the lodes worked by the Krupp Company, in the Georg and Harxborg mines near that place. Pyrolusite, göthite, rhodochrosite, copper pyrite, sphalerite, galena, boulangerite and gray copper ore occur alongside of the spathic iron ore. In the Luise mine an intrusion of basalt has transformed the spathic iron ore at that place into magnetite.

A lode which has become famous for its rare minerals is the siderite lode of the Friedrich and Eisengarten mines of the Hamm district.[2] This vein traverses lower Devonian rocks. Besides siderite it also contains nests and stringers of sulphidic ores, mainly galena and chalcopyrite, also zinc-blende, pyrite and bornite. In the siderite ore of the hanging-wall split of the vein, a great nest of ore was struck in 1884, consisting of filiform niccolite, hauchecornite (a nickel bismuth sulphide) and kallilite (bismuth antimony nickel glance).

Analogous veins occur in the green Paleozoic sericitic and chloritic schists of upper Hungary.[3] Now only spathic iron ore is obtained, especially at Kotterbach in the Zips. The two most important lodes striking west-northwest and dipping steeply south are the Drozdziakow lode and the Grobe lode. The former is at points 25 to 30 meters (82-98 ft.) thick, and is usually split up into two stringers from 2 to 6 m. (6.5 to 19.6 ft.) thick. The lower one carries much gray copper ore and copper pyrite in bunches or in parallel layers in the spathic iron ore, whereas otherwise the structure is purely massive. The coarse-grained crusts of the Grobe vein consist of siderite and barite together with some quartz and calcite and much copper pyrite and mercurial tetrahedrite. Sometimes the barite entirely displaces the siderite of the veins and in isolated cases specularite occurs in lenticular patches. In the ferruginous gossan, cinnabar and native quicksilver are found, besides malachite, azurite and native copper. These peculiarities serve to indicate that the veins are closely related to the spathic copper deposits (q. v.).

No veins of this type are now worked in the United States, though a 6 to 8 ft. vein in gneiss at Roxbury, Conn., was formerly mined. It consists of crystalline siderite with a little quartz and a variety of metallic sulphides. The type is a transition to the sideritic silver lead deposits, such

[1] Hilt: 'Die Eisensteinlagerstätte der Grube Louise bei Horhausen,' etc., *Z.* f. d. B. H., u. S. im preuss. St., Vol. XIII, 1865, p. 13.

[2] Wolff: 'Beschreibung des Bergreviers Hamm a. d. Sieg.' Bonn, 1885. C. Leybold: 'Geogn. Beschreibung der Eisenerzgruben Wingershardt, Friedrich, Eisengarten,' etc. *Jahrb.* d. k. preuss. geol. Landesanst., 1882, pp. 3-47. R. Scheibe: 'Ueber Hauchecornit, ein Nickelwismuthsulfid,' *Jahrb.* d. k. preuss. geol. Landesanst., 1891, p. 91 *et seq.*

[3] Faller: 'Reisenotezen,' etc. *Jahrb.* d. k. k. montan.Lehranst., 1867, p. 132.

as those of Cœur d'Alene, where as a gangue the siderite is worthless. Similar ores occur in the Slocan district, B. C., and Wood river, Oregon.

2. *Veins of Red Hematite.*

These veins consist of dense, earthy and fibrous red hematite, together with quartz, jasper, ferruginous quartz and more rarely carbonspars, barite and manganese ores.

This class of veins is common in the Saxon Erzgebirge in the contact area about the great granite stocks in the vicinity of Schwarzenberg.[1] Some of the veins occur on the contact plane between crystalline schist and granite, others are in granite itself. The Rothenberger vein is the most important. Besides the minerals mentioned above, copper ores occasionally occur. A notable feature is the frequent occurrence of pseudomorphs of quartz, limonite and red hematite after calcspar, more rarely after barite anhydrite and fluorspar, or of mere impressions of crystals of the last mentioned minerals. These show that the original vein filling has undergone great changes. The vein structure is either massive or brecciated. These veins are 10 or even 20 meters (33—66 ft.) thick, and cut through the barren "quartz-brockenfels" veins and stocks of the region. Among the miners of that locality the expressions *'red,' 'black' or 'brown'* stringer were formerly current. This fact indicates the frequent change in the development of these lodes in which red hematite, manganese ores, brown hematite or iron ocher prevailed by turns.

In the Harz, especially in the region of Zorge, a somewhat different type occurs, consisting of veins of red and brown hematite in diabase. The ores were certainly formed as a consequence of lateral secretion, and the veins become barren when they pass from the diabase to silicious schist or graywacke.[2] Their origin is disclosed by the fact that red hematite also fills the interspaces between the decomposition boulders of the diabase.

Many lodes of brown hematite undoubtedly originally contained red hematite, while in others it is impossible to tell whether the original ore was red hematite or spathic iron ore, as, for example, in the veins of Bergzabern, in Rhenish Bavaria, which cut Triassic sandstone.[3] Small stringers of brown hematite are a common phenomenon in all sandstone areas

[1] A. Breithaupt: 'Paragenesis,' 1849, p. 195. H. V. Oppe: 'Die Zinn- und Eisenerzgänge der Eibenstocker Granitpartie und Umgebung,' Cotta's *Gangstudien*, II, 1854, p. 133.

[2] Von Groddeck: 'Erzlagerstätten,' 1879, p. 153.

[3] B. v. Cotta: 'Erzlagerstätten,' II, p. 170.

of the world, but while deposits of specular hematite are abundant in America, no true veins of the type are now known to be worked.

3. *Veins of Manganese Ores.*

Manganese ores, especially pyrolusite, psilomelane, braunite, manganite, polianite, more rarely hausmannite and wad, accompanied in most cases by oxide iron ores, are associated with quartz, barite and calcspar as gangues.

There are numerous deposits of this kind in Saxony in the vicinity of Schneeberg, Aue and Schwarzenberg, which are found in part in granite, in part in contact metamorphic schists.

In the vicinity of Langenberg, not far from Schwarzenberg, the veins are found to be directly connected near the outcrop, with very peculiar stratiform deposits of an efflorescent iron-manganese ore. These deposits either fill flat basin-shaped depressions, overlaying the prevailing mica schist cut

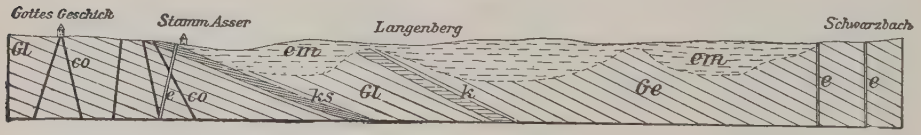


Fig. 141.—Profile from Gottes Geschick to Schwarzbach. (H. Müller.)
gl and ge, mica schist; ks, pyrite bed; k, bed of dolomitic limestone; em, efflorescent iron manganese ore and quartz-brockenfels; e, veins of the iron manganese formation; co, veins of the silver-cobalt ore formation.

by the veins, or they form stocks in the midst of the schist. These stocks seem to be the result of lateral impregnation and metasomatic replacement of certain beds of the country rock (Fig. 141). These deposits are intimately connected with great veins of iron and manganese ores which often swell into stocks called 'quarzbrockenfels' because of their brecciated structure. Cobaltiferous manganese deposits of this type occurring near the outcrop of cobalt veins cutting mica schists in the mines near Graul (Fig. 141) enclose rich and sometimes large fragments of siliceous bismuth ochre. These mines during the last decade showed a considerable output of bismuth and cobalt ores; in 1898 they produced 2,726 tons of these ores. A more detailed description of these efflorescent manganese ore deposits is given by H. Muller[1] and R. Beck.[2]

[1] 'Die Erzgänge des Annaberger Revieres,' Leipzig, 1894, p. 104. (Erläut d. geol. Spezialk.)

[2] 'Erzlager von Schwarzenberg,' part I, Freiberger *Jahrbuch*, f. d. B. u. H., 1902, p. 64.

The manganese veins of Ilfeld in the Harz mountains occur, according to O. Schilling,[1] in a hornblende porphyrite mass which is occasionally, as at Möncheberg, completely penetrated by their stringers. The veins are for the most part only a few centimeters thick and usually grow poor at 12 meters; only in exceptional cases have they been followed down as far as 60 meters. Their filling consists of manganite, pyrolusite, varvicite, braunite, hausmannite, psilomelane and wad, besides barite, calcspar, brownspar and manganspar. Their manner of occurrence shows that their origin is due to lateral secretion.

In the Thuringer Wald there are deposits of this class at Rumpelsberg and the Mittelberg near Elgersberg in veins in porphyry. Other veins which occur in porphyry in Thuringia possess a brecciated structure, and according to H. Credner,[2] the manganese ores are practically free from gangue. At the present time they are still worked at Arlesberg (Morgenstern mine).

In the Oerenstocker district other veins occur partly in porphyry, partly in melaphyre, and at Friedrichsrode a melaphyre conglomerate forms the country rock of such fissure fillings. At Friedrichsrode fissure veins traverse a melaphyre, the ores occurring in remarkably well defined bands and crusts 1 to 3 centimeters thick, parallel to the vein walls.[3] The manganese minerals alternate with layers of calcspar, and barite is usually intergrown with them.

Manganese veins occur in granite near Wittichen in the Black Forest, west-southwest of Santander in northern Spain.[4]

The manganese lodes of the Veitsch in Styria are quite different. The headwater valleys of the Veitsch, especially the Kaskögerl and Friedelkogel, consist, according to M. Vacek,[5] of Silurian limestones traversed by strike fissures filled with manganese ores. According to analyses by C. von John the latter consists solely of rhodochrosite. These deposits were formerly regarded as beds. Mention may here be made of the lodes at Romaneche in France, to be referred to later. (See under 'Primary Differences in Depth.')

Although manganese minerals are common constituents of mineral veins, workable deposits of this type are rare. This is probably because an ore carrying less than 40% is not ordinarily marketable. The world's production comes mainly from concentration due to weathering.

[1] Geol. Spezialkarte, 'Norhausen Blatt,' 1870, p. 9.
[2] H. Credner: 'Geol. Verh. d. Thür. Waldes und d. Harzes,' 1843, p. 130.
[3] Cited by Breithaupt, 'Paragenesis,' p. 195.
[4] *Zeit. f. Prak. Geol.*, 1897, p. 90.
[5] M. Vacek: 'Ueber die geol. Verh. des Flussgebietes der unteren Mürz,' *Verh.* d. k. k. geol. Reichsanst., 1886, p. 459. C. v. John. *Jahrb.* d. k. k., Reichsanst., 1886, p. 344.

(β) Veins of the Tin Ore Class.

4. Tin Veins.

I. *General Remarks.*

The most important ore-minerals of tin deposits are cassiterite, wolframite (tungsten), native bismuth, arsenopyrite and löllingite,[1] molybdenite and scheelite; more rarely stannite, bismuthinite, specular hematite, iron spar, chalcopyrite and other copper ores, magnetite, stolzite (lead tungstate), as well as the secondary minerals scorodite, pharmacosiderite and bismuth ochre. In the gangue, quartz and lithia-mica are most common.

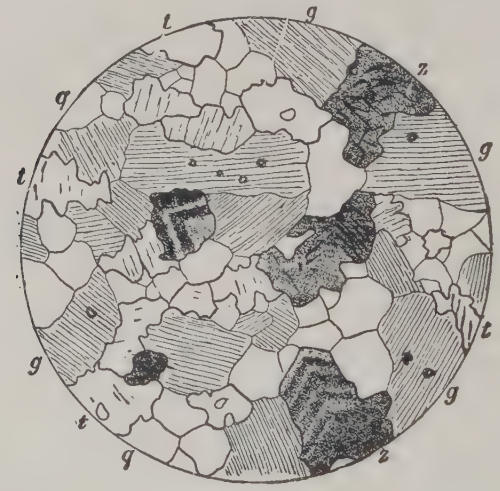


Fig. 142.—Thin section of a greisen from Banka, enlarged fifty times.
q, quartz; g, mica, with dark aureoles around zircons; t, topaz; z, tinstone. (*Zeit. f. Prak. Geol.*, April, 1898.)

Orthoclase, gilbertite, topaz and its fibrous variety, pycnite, fluorspar, apatite and tourmaline are also frequent. Beryl, herderite PO_4Ca [Be(OH,F)] and triplite PO_4 (Fe,Mn) [(Fe,Mn)] are rarer. Tin veins occur associated with granites that carry lithia-bearing mica and cassiterite among their normal ingredients; sometimes their silicates also contain some tin. A few deposits are found associated with acid eruptive rocks, rhyolites and trachytes. The lodes cut through the eruptive masses, as well as the other country rocks, the rocks showing a peculiar and characteristic alteration adjacent to the veins. By this alteration the feldspars

[1] $FeAs_2$. Probably also leucopyrite, Fe_3As_4.

have been destroyed and in their place quartz, lithia mica, topaz and tinstone, and often tourmaline also have been deposited. This altered rock is called greisen when derived from granite, the alteration product of the other rocks having no special name, being simply called tin ore. The accompanying figure (142) represents a thin section of a typical greisen of a coarse-crystalline variety.

The structure of the original rock, as, for example, the porphyritic structure of many granites, is often exhibited in the structure of the greisen. The large masses of feldspar formed, in such cases, the main points of attack by the invading tin compound, as proved by the fine pseudomorphs of tin ore after orthoclase which have been obtained from the Botallack mine in Cornwall.

The bands of greisen and tin ore, though mostly no thicker than a finger or a hand's breadth, and rarely as much as a meter thick, are often the real object of mining operations because of their great abundance and bulk despite their great poverty, while the true veins or fissure filling, being for the most part narrow, rarely pay for working. However, in some cases the true fissure filling is one to three meters wide, consisting in such cases of quartz, having a massive structure or only showing a symmetric banding when considerable lithia-mica is present.

Cassiterite or tinstone, the most important ore of the formation, occurs crystallized in several types: (1) In more or less perfectly developed twinned crystals and crystalline grains, as, for example, in Saxony and Bohemia; (2) in simple columnar crystals called 'needle-tin,' in Cornwall; according to Becke, the hematite-like, so-called wood tin ore of Cornwall and Bolivia belongs to this group; (3) in compact masses suggesting brown hematite, in which form it is thus far known only from Bolivia.

The probable mode of origin of the tin lodes is discussed further on in this work.

Besides the strictly typical examples of this class, there are also transitions toward the tourmalinic copper type, the pyrite-blende-lead deposits and the rich silver ore formations (silver-quartz veins).

Among the numerous occurrences found in nearly all parts of the globe, only the most important are selected as examples.

The European mines are at present competing with difficulty with the mines of the East Indies and Australia. They are in part also actually exhausted. The most important are those of the Erzgebirge of Saxony and Bohemia, and the mines of Cornwall and Brittany.

In the Erzgebirge the districts richest in tin are those of Altenberg, Zinnwald and Graupen; further west, in the vicinity of Ehrenfriedersdorf and Geyer, Eibenstock, Johanngeorgenstadt and Platten. The tin production

of the Erzgebirge reached its maximum before the fifteenth century, with about 250 tons a year, and since then has steadily declined.

II. *The Tin Deposits of Altenberg, Zinnwald and Graupen.*[1]

Between Dippoldiswalde and Teplitz the Erzgebirge is traversed obliquely by a north-south zone of fracturing along which vast eruptive masses have come up; first, the long extended stock of Teplitz quartz porphyry running north and south, spreading out from the feeding fissure of the eruption as a sheet covering both the gneiss, in which the fissure occurs, and also the adjacent Carboniferous and Permian strata. The second eruptive mass is granite porphyry occurring in several broad dikes, one of which forms the eastern boundary of the Teplitz porphyry stock for a great distance. Finally, and latest in time, a number of granite stocks were formed, piercing the two preceding intrusive masses. At Altenberg a small granite stock of this kind pierces the granite porphyry. As the Teplitz porphyry eruptions belong to the period of the Rothliegende, the granite is of post-Permian age. A feldspar (nearest to albite), a dark lithia-bearing potassium-iron mica, with cassiterite and topaz as accessories, are its chief constituents. Both the granite and its enclosing rock are traversed by innumerable small stringers of tin ore, each quite insignificant by itself and often hardly perceptible, but accompanied by adjoining zones of ore. Figure 143 represents a piece of Altenberg granite with ore bands of this nature. In some of the fissures the filling consists of quartz and topaz. Many bands that are not thicker than a knife-blade are noticeable only by reason of their whitish color. In the rocks lying above the dome formed by the granite intrusion, these small veins are so closely crowded, and the country rock so strongly impregnated with ore, that is to say, transformed into tin-bearing greisen, that this 'stockwork' was formerly exploited on a large scale by extensive drifts. This Altenberg tin stock, so far as known from exposures thus far made, continues only to a depth of about 230 meters (754 ft.) below the summit of the granite dome. At a greater depth there are merely a few narrow impregnation fissures scattered through the otherwise normal granite, as shown in the accompanying section (Fig. 144).

[1] Most important publications: G. A. von Weissenbach: 'Die Zinnerzlagerstätten von Altenberg und Zinnwald,' 1823. Manuscript in Freiberg. H. Müller: 'Bildung der Zinnstockwerke.' Berg u. Hütten. Zeit., 1865, pp. 178-180. E. Reyer: 'Zinnerzführende Tieferuptionen von Altenberg und Zinnwald.' *Jahrb.* d. k. k. geol. Reichsanst, 1878. H. Zinkeisen: 'Geognostisch-mineralogische Beschreibung der Gegend von Zinnwald und Altenberg,' 1888. Ms. in the Kgl. Bergakademie. K. Dalmer: 'Sect. Altenberg-Zinnwald der Specialk. von Sachsen nebst Erläut, 1890 und Ueber den Altenberg-Graupener Zinnerdistrict,' *Zeit. f. Prak. Geol.*, 1894, pp. 313-322. See also publications of R. Beck in *Zeit. f. Prak. Geol.*, 1896, pp. 148-150, and general account by E. Reyer, 'Geologie des Zinnes,' 1881.

The cassiterite content of the ores mined at Altenberg varies between 0.1 to 0.9%. The tin-stone granules are very small, mostly only 0.01 to 0.1 millimeters in diameter, and, as a rule, are not visible to the naked eye. Between 1869 and 1887 the ore treated averaged 0.3% Sn and 0.002% Bi. Only its great quantity makes it possible to work this very low-grade rock. Altenberg was discovered in 1458 and at first, probably during the time when the loose granite débris covering the granite boss was washed, it gave a very rich yield, 5,000 to 6,000 centners of tin per year. The Zwitterstock Company was founded in 1546 and is still in existence.

Fig. 143.—Granite of Altenberg with Zwitter bands. (From nature.)

After various small subsidences the workings completely collapsed in 1620, forming the great basin seen to-day. From that time to the present day mining has been confined to the caved-in area. Real vein mining has been carried on in some of the larger tin ore veins, but only to a very subordinate degree. In 1898 the production of Altenberg had declined to 14 tons of tin, but it has risen again during the last four years.

A different state of affairs exists at Sächsisch Zinnwald and Böhmisch Zinnwald to the south of Altenberg, where not only has tin-bearing greisen been extracted, but a lively mining industry has been prosecuted upon the

true fissure filling of the tin lodes of this place. At present the lodes are worked mainly for wolframite and lepidolite, and all the old dumps have

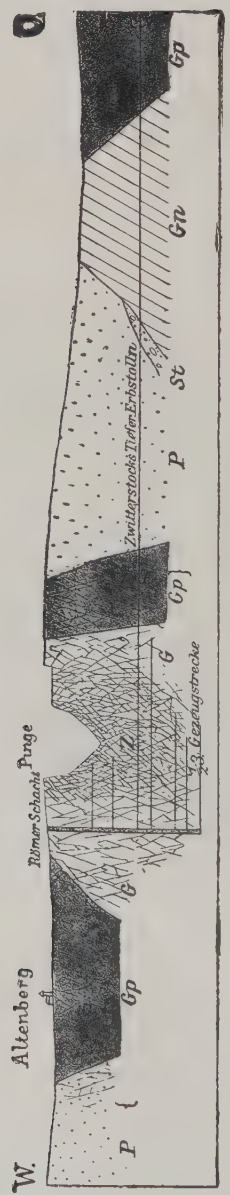


Fig. 144.—Section east-west through Altenberg. (Dalmer.)
P, Teplitz quartz porphyry; Gp, granite porphyry; G, granite; Z, Zwitterstock; Gn, biotite-gneiss; St, conglomerate and sandstone of Carboniferous coal measures.

been turned over several times for these formerly worthless minerals, which are now much in demand.

The mines are exceedingly rich in wolframite, and about 1900 the demand for this mineral gave rise to a rejuvenation of the Zinnwald mine, which was discovered about the middle of the fifteenth century, had its cli-

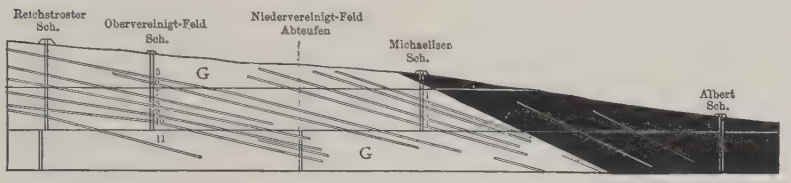


Fig. 145.—Section through the north part of the Zinnwald granite stock.

G, granite mostly altered to greisen. Dark area on right side Teplitz quartz porphyry. 1–4, Michael seam; 5, day seam; 6, upper seam; 7, organ seam; 8, middle seam; 9, upper pyritic seam; 10, lower pyritic seam; 11, lean seam.

max of prosperity about the middle of the sixteenth century, but of late years was merely able to maintain a modest existence. In 1899 Sachsisch Zinnwald produced 50 tons of wolframite.

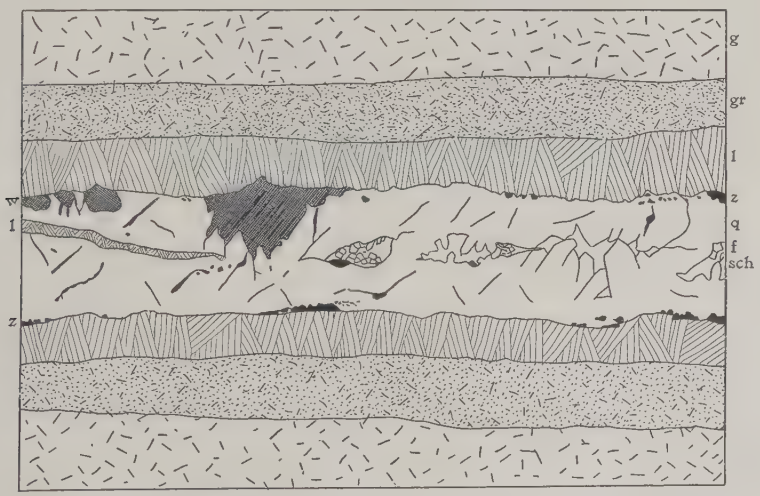


Fig. 146.—Ideal section of a so-called tinstone seam in granite at Zinnwald.

G, granite; gr, greisen; q, quartz; l, lepidolite; z, tinstone; w, wolframite; f, fluorspar; sch, scheelite.

At Zinnwald only the summit of a granite dome intruded in the Teplitz porphyry is seen exposed, the surface of the dome dipping gently in all

directions under the porphyry. Close to the contact the granite sometimes assumes a coarse-grained development, otherwise it is medium-grained. As shown by the profile (Fig. 119), the upper portion of this dome contains a number of parallel veins which may be compared to flat inverted bowls; because of their horizontal or gently dipping position these are called seams or beds (flötze). The veins are not exactly parallel to the contact plane between the granite and the porphyry, as the dip is somewhat lower, and the veins therefore occasionally pass into the adjoining porphyry, where, however, they grow poor (see Fig. 145).

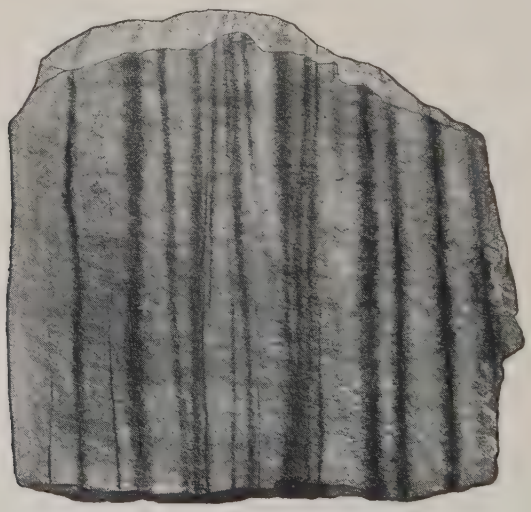


Fig. 147.—Specimen of Teplitz quartz porphyry cut by parallel bands of ore. (Zwitter.) (From nature.)

Sometimes two such veins converge into a single one. They usually consist of quartz with a selvage zone of lepidolite, on each side, as shown in Fig. 146. Only rarely is the quartz replaced by orthoclase. Along the middle of the vein, druse cavities are abundant and are lined with quartz crystals sometimes 30 cm. long and 17 cm. thick. Some of these projecting crystals are built up of quartz 'caps' consisting of several layers, between which minute mica scales have produced planes of parting. Crushed quartz crystals are often found, whose fragments are again encrusted by quartz, a phenomena indicating a continued growth for considerable periods. The cassiterite, also, is not all of one generation, since broken crystals occur whose fracture surfaces are studded with smaller individuals. Ordinarily the cassiterite and wolframite are most abundant at the selvage, or between

the mica bands and the quartz, but they also occur in irregular transverse rows of granules and stringers, which rarely attain a thickness of two centimeters. Sometimes the wolframite may occupy almost the entire fissure, as shown in the latest great mining developments. Among the commoner ores, scheelite (tungstate of lime) is the youngest, and is found by preference in the quartz druses, often cementing quartz fragments, and often accompanied by fluorspar. The less abundant minerals of the lodes include topaz (as pycnite), black tourmaline, apatite, uranium mica, zeunerite ($CuU_2As_2O_{12} + 8\ H_2O$), specular hematite, spathic iron ore, stolzite (lead tungstate); finally, copper pyrite, gray copper, arsenopyrite, tin pyrite, galena and zinc-blende. The thickness of the bed-like veins varies between 15 and 70 centimeters, but may also reach 1.5 and 2 meters (4.9 to 6.5 ft.); about twelve of them have become economically important. Some steep-dipping tin veins are also known in the locality. Both horizontal and vertical veins are accompanied by bands of greisen on each side. Extensive drifts, especially in the Reichstroster Weitung, have developed some very large masses of greisen within the Zinnwald granite, which cannot be referred to any recognizable impregnation fissures. Probably they owe their origin to an immense number of minute fissures like those of the Altenberg stockworks. Younger veins of barytic ores also occur. The adjoining quartz porphyry also contains numerous narrow bands of ore traversed by narrow veins of a fine-grained aplite-granite (alaskite), representing later phases of the normal granite of the stock. *The impregnation with tinstone occurred, therefore, before the last phase of the eruptive activity in that region.* The accompanying representation of a platy fragment of quartz porphyry from the Hoffnung Gottes Erbstolln at Zinnwald shows the manner in which the rock is traversed by a great number of parallel bands of tin ore succeeding one another at short intervals (Fig. 147).

The tin veins formerly worked contained 0.2 to 0.8% of tin, and about 1 to 2% of tungsten, while the greisen, which was picked out and treated in the stamp mill, gave 0.2 to 0.5% tin, and was very low in tungsten. In 1898 Sachsisch Zinnwald produced 50.5 tons of tungsten, 116.8 tons of lepidolite and only 1.2 tons of limestone.

In the Graupen[1] region on the south slope of the eastern Erzgebirge tin ore has been produced since the end of the twelfth century, at first from the gravel in the extensive alluvial fan at the mouth of the Graupen valley

[1] Important publications: Th. Schiller and P. Lewald: 'Das Zinnerzvorkommen zu Graupen,' etc., in H. Hallwich. Geschichte von Graupen. Prague, 1868. R. Beck: 'Erläuterungen zu Section Mückenthürmchen der geol. Spezialkarte von Sachsen.' Leipzig, 1903. A monograph on the Graupen district by the same author is in preparation.

near the present town of Mariaschein. The ores at Steinknochen and at the Mückenberg, near Obergraupen, as well as at the Knotel further down the mountains, were developed next, and for some time mining was also carried on in a number of impregnation fissures at the Preisselberg Klösenberg and at the Zwicken basin. An insignificant mining industry still continues in the Martinistolln.

The tin ores of Graupen are genetically connected with a granite mass and with granite dikes which cut through both the gneiss and in part also the porphyry rocks of that region. A characteristic feature of the Graupen tin lodes is the large amount of orthoclase (micro-perthite) and of fluorspar in the lode filling. Where quartz and lithia-mica predominate, the rock alongside of the veins is altered to a zone of tin ore rich in topaz.

The Schellerhauer granite stock,[1] west of Altenberg, is also associated with tin veins, and further northwest, at Pöbel at the Sadisdorf basin, veins of copper-tin ore were formerly worked, which pass into a granite stock in depth.

In the Seiffen mine, on the other hand, impregnation fissures in gneiss with tinstone and copper ores were worked. No granite was encountered, although it may be presumed to exist at a greater depth.[2]

III. *The Deposits of Geyer and Ehrenfriedersdorf.*

In the western Erzgebirge, near the town of Geyer, a zone of mica schist is broken through by three small granite masses. This rock, which is rich in topaz, is accompanied by tin veins at Greifenstein, Zinnberg and Geyersberg. The most important mines of former days were those of Geyersberg, which have formed a basin on the surface by their collapse. A characteristic feature of the granite of Geyersberg is the 'stockscheider,' a very coarse, crystalline 'giant granite' developed in the porphyry of the stock near its contact with the mica schist. It forms a granite dome or boss, for the most part concealed, but with the apex showing in outcrop as the Weisse Erdenzeche near Aue, where it is decomposed and used as a porcelain clay. This Geyersberg stock, 240 meters wide, whose upper surface dips at 50 to 60 degrees in all directions beneath the schists, is traversed near its top by innumerable tin-bearing fissures varying up to five centimeters thick, striking northeast to east and dipping northwest at 70 to 80°. They are grouped in 19 series, and together with the greisen zones on both sides, which attain 10 centimeters across, are called 'streams,' and are exploited by drifts. These lodes contain quartz, topaz, mica and tinstone; also fluorspar, tour-

[1] F. Schalch: '*Erläut.* Zu Section Dippoldiswalde Frauenstein,' 1887, p. 17.

[2] J. F. W. v. Charpentier: 'Mineralog. Geographie,' 1778, p. 133. H. Müller: 'Die Erzgänge des Freiberger Bergrevieres.' 1901, pp. 130-138.

maline, geyerite and arsenopyrite rich in arsenic; more rarely wolframite, native bismuth, molybdenite and triplite, as well as apatite.

The conditions at the Geyer mines are shown in two figures. One of them (Fig. 148), taken from the work of Charpentier[1], cited below, takes us back to the times of fire-mining. It gives a good view of a series of lodes, showing distinctly how several parallel vein stringers are accompanied on both sides by impregnation zones, which fade away in a cloudy, blurred fashion toward the brighter, normal granite. The second (Fig. 149) is a photograph of a sample from the lode. The broader stringer is about one centimeter thick, and besides the predominant quartz, it carries along the middle a line of dark-looking tinstone and mica. The granite in the vicinity of the two stringers has, with the exception of a small remnant at the left edge, been altered to gray greisen.

Mining began at Geyersberg in 1315. In 1803 the works caved in, forming a great hollow. A quarry in this basin now affords excellent exposures of the vein structure.

Until lately the tin veins northeast of Geyer near Ehrenfriedersdorf were also worked. At the Sauberge these lodes are united into an entire series, the so-called 'rissen' traversing the mica schist, which have long been famous for their fine crystals of tinstone and apatite. They also carry colorless tourmaline, anatase, arsenopyrite, chlorite, fluorite, molybdenite, scheelite, wolframite, gilbertite, herderite and barite. They intersect rich barytic silver veins, and at the meeting the two ores are said to blend; they also traverse older dikes of mica diorite. Granite has not been found here, but may possibly exist at no great depth.

Tin veins were also formerly worked at numerous places in the peripheral parts and within the contact area of the Eibenstock granite massive, for example, at Aue, Sosa, Burkhardtsgrün near Schneeberg, at Auersberg near Eibenstock, at Gottesberg, at Schneckenstein near Auerbach, at Johanngeorgenstadt, and at Platten. At Hengstererben near Platten the Sanct Mauritius mine was opened again in recent time, toward the end of the seventies. The Eibenstock granite carries tinstone microliths among its primary ingredients, as all the granites associated with tin ore deposits (Altenberg, Schellerhau, Banka) probably do. Furthermore, according to Stelzner[2] and others, the silicates composing this granite also contain some tin, namely, the dark lithia-iron mica, 0.32%; the orthoclase, 0.019%; the plagioclase (albite), 0.074% SnO_2. This granite is more-

[1] J. F. W. v. Charpentier: 'Mineralog. Geographie der Chursächs. Lande.' 1778. A. W. Stelzner: 'Die Granite von Geyer und Ehrenfriedersdorf, sowie die Zinnerzlagerstätten.' Freiberg, 1865.

[2] A. W. Stelzner: 'Entstehung der Freiberger Gänge.' *Zeit. f. Prak. Geol.*, 1896, p. 394.

over rich in tourmaline as well as in topaz, a feature typical of the granites associated with tin ores. The adjoining schists metamorphosed into andalu-

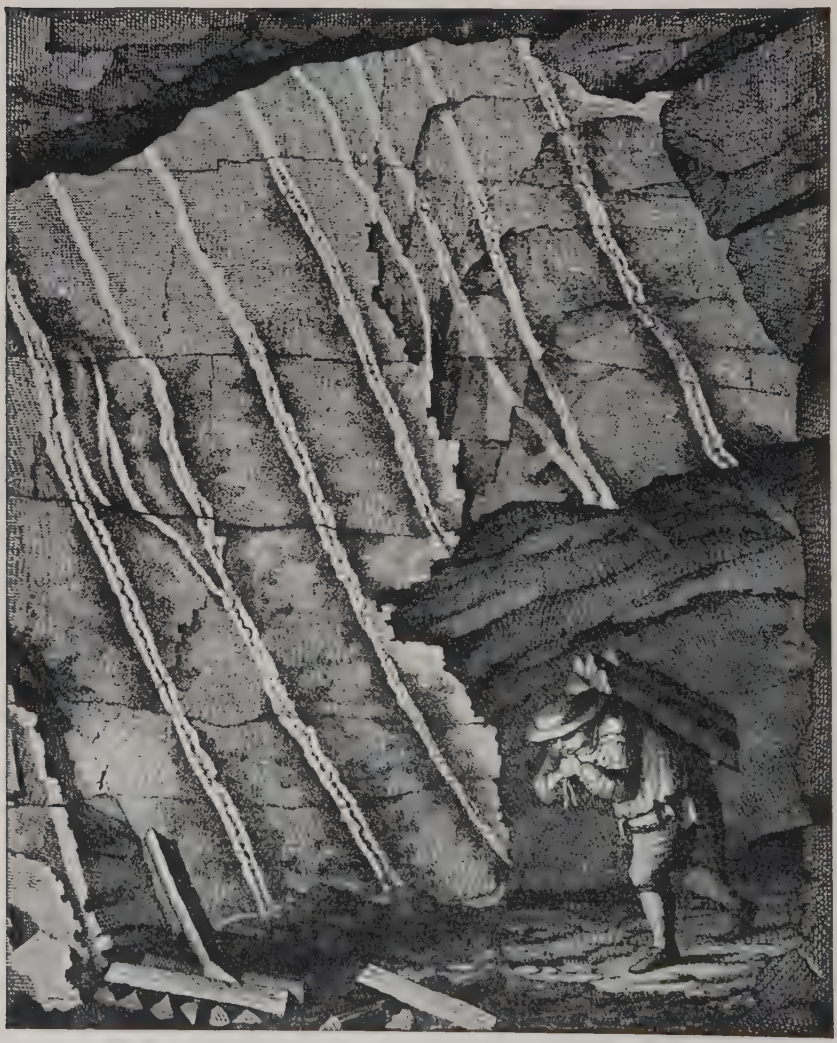


Fig. 148.—Tin veinlets of the Geyer stockwork. (Charpentier.)

site-mica rock, etc., have often been impregnated along minute fissures by tourmaline associated with tinstone. Such tinstone-bearing tourmaline schists were formerly worked at Auersberg. The well-known topaz rock

of the Schneckenstein, near Auerbach, represents a breccia of such tinstone-bearing tourmaline schist, whose cement consists of quartz and topaz.

The Eibenstock granite area is connected geologically with that of Carlsbad of Bohemia; here, too, at Schlaggenwalde, the contact zone between granite and gneiss contains tin veins closely resembling those of Ehrenfriedersdorf and Geyer. As early as the fourteenth century an active mining industry flourished there, its center being the town of Schoenfeld.[1]

Fig. 149.—Two tin ore veinlets from the Geyer stockwork.

The tin production of Bohemia in the sixteenth century, when it reached its climax, is estimated to have been 500 to 800 tons per year (H. Louis). At present it is hardly worth mentioning.

IV. *The Tin Deposits of Cornwall.*

The tin deposits of the peninsula of Cornwall are of far greater importance than those of the Erzgebirge. In this region the slates, which are

[1]K. Sternberger: 'Die ärarischen Bergbauunternehmungen im böhm. Erzgebirge in Oesterr.' *Z.* f. B. u. H. 1857., p. 62.

mostly of Devonian age, are traversed by five large and several small stocks of tourmaline-bearing granite. Both the slates, locally called *killas,* and the granite are cut by numerous dikes, some as much as 120 m. (393 ft.) thick, of quartz porphyry, also tourmaline-bearing, called *elvans.* These dikes also traverse carboniferous rocks (Culm). The granite intrusions, whose contact generally dips gently below the slates, have caused considerable contact metamorphism, transforming the slates into green, purple and violet hornfels and similar rocks. All these rocks are traversed by lodes of copper and tin ores,[1] which show a great tendency to break up into stringers, and often pass into an exceedingly fine network of veins. These are especially numerous near the granitic masses. Their strike is mostly between east and east northeast; their dip is ordinarily 20 to 50° north. The thickness may rise to 1.5 meters, but is mostly much less. The principal gangue is quartz, with associated orthoclase, tourmaline, chlorite, lithia-mica and some fluorspar. The tin veins contain cassiterite, stannite, copper pyrite, tungsten, blende, arsenopyrite, native bismuth and other rarer minerals; the copper lodes proper also contain gray copper, tennantite, cuprite, native copper, malachite, azurite, pyrite, arsenopyrite and blende. A remarkable feature is the change in the nature of the ore in many lodes when they pass from the slate into the granite, the pure copper becoming tin deposits.[2] This is especially well shown in the longitudinal section (Fig. 150) of the Dolcoath mine, and the cross-section of the same lode (Fig. 151) gives a striking illustration of the stringer formation of those lodes. Some lodes are filled by a breccia enclosing many fragments of the country rock; but the vein filling is generally massive, in some cases showing a symmetric banded structure. The veins are accompanied by zones of impregnation, some of them very wide, which are also worked for tin, and have furnished the main bulk of the ores turned into the furnace.

While the vein fissure itself is often only a few centimeters thick, the 'lode' as worked is several meters in thickness, and is formed of granite altered to greisen.[3] The so-called Carbonas of St. Ives is worked for tin ore to which its high content of tourmaline imparts a dark color. This greisen rock forms very irregular deposits connected by a transverse fissure with one of the main lodes of that locality. These deposits consist mainly of feldspar, quartz, tourmaline and cassiterite, associated sometimes with

[1] W. J. Henwood: 'On the Metalliferous Deposits of Cornwall.' *Trans.* Roy. Geol. Soc. of Cornwall, Vol. V, 1843. H. T. De la Bêche: *Rep.* on geology of Cornwall and Devon, 1839. C. Le Neve Foster has published many papers on this district since 1875 in *Trans.* Royal Geol. Soc., Cornwall.

[2] C. Le Neve Foster: *Mining,* 1883, p. 452.

[3] C. Le Neve Foster: 'On the Great Flat Lode South of Redruth,' etc. *Quart. Journ.* Geol. Soc., 1878, Vol. XXXIV, p. 640.

fluorspar, lithia-mica, copper pyrite and iron pyrite.[1] In the slate, also, the altered rock of the zones of impregnation is rich in cassiterite and is mined, being called *capel*. This dark-colored rock consists mainly of quartz and tourmaline, with short quartz stringers interpolated, and is traversed by small stringers of tinstone and chlorite. These *capels* accompany the cassiterite veins ('leaders').

The most important tin vein in Cornwall is the Dolcoath lode, already mentioned, which for a length of 2.25 miles is worked in the Carn Brea, Tincroft, Cook's Kitchen and Dolcoath mines. The last named mine at present furnishes one-third of the production of Cornwall.

The richness of Cornwall in tin ore was known to the ancients and gave to Great Britain the name of Cassiterides. The greatest annual production of tin ore was 16,759 tons in 1871. It had declined to 12,880 tons in 1894, and is annually diminishing, being but 4,700 tons in 1901. Copper mining, proper, only began in 1700. In 1838 the yearly production was 145,000 tons, but in 1894 it was only 3,370 tons. Copper-tin ore deposits, quite analogous to those of Cornwall, are also found in the adjoining county of Devonshire.

In France, tin deposits of similar nature occur in Brittany; for example, at Pyriac, west of the mouth of the Loire, and at Villeder in the department of Morbihan, but are at present of no economic importance.

The tin veins of Montebras are worked mainly for amblygonite.[2]

Among the occurrences of the Iberian peninsula we may mention those of Santo Tomé, south of Salamanca, and at Cartagena in Spain, as well as those of Ramalhoso near Amarante in Portugal, province of Beira. Some of the Spanish lodes are particularly rich in wolframite. In 1900 Spain produced about 1,958 tons of wolframite.

V. *Tin Districts Outside of Europe.*

Among the tin deposits of other countries, the first and most important are those of Banka and Billiton and those of the Malay peninsula.

The lodes of Banka and Billiton,[3] the so-called "tin islands," occur in granite or older schists. Besides quartz and cassiterite, they nearly all contain magnetite, some also tourmaline, and some tungsten, or else pyrite, and spathic iron ore, so that their mineralogic character presents considerable variety. The remarkable occurrence of true magnetite veins in that

[1] W. J. Henwood, *op. cit.*, 21.

[2] J. H. L. Vogt: *Trans.* Am. Inst. Min. Eng., 1901, p. 11.

[3] Th. Posewitz: 'Das Zinnerzvorkommen und die Zinnerzgewinnung in Bangka,' 1886. R. D. M. Verbeek: 'Geologische Beschrijvning van Bangka en Billiton.' 1897. R. Beck: *Zeit. f. Prak. Geol.*, 1898, part 4, gives many references.

locality is also noteworthy. The lumps of tinstone weighing more than 1,000 kilograms found in the eastern part of Billiton seem to have been derived from the upper portion of the tin lodes. Alongside of the lodes

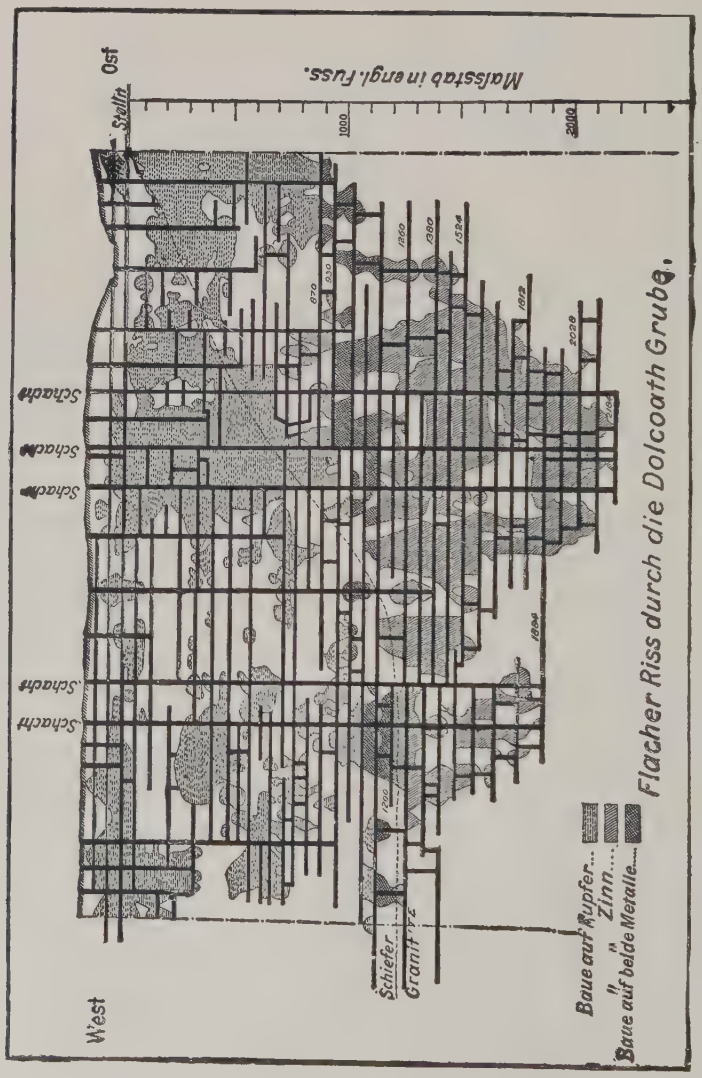


Fig. 150.—Longitudinal section through the Dolcoath lode. (Le Neve Foster.)

the granite has here and there been transformed into greisen, rich in tinstone and topaz. (For geological occurrence and description see chapter on tin placers.)

On the Malay peninsula special mention must be made of the deposits of Malacca on the west side and of Kuantan[1] on the east side. However, by far the greater part of the supply of Malacca tin is obtained from placer gravels.

Siam and China are also to be mentioned as Asiatic tin producers, and in Japan the Taniyama mine in the Province of Satsuma is located on a tin lode (see 'Copper in Japan').

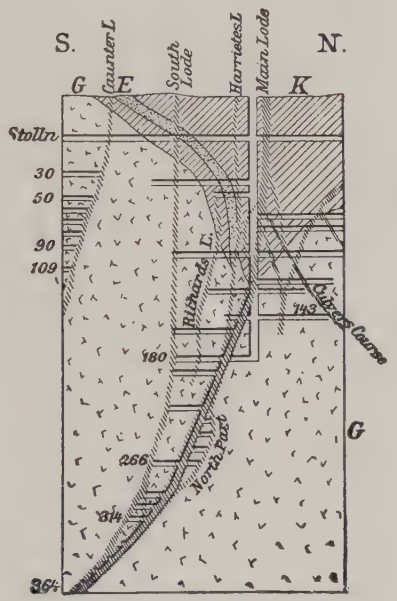


Fig. 151.—Cross-section through the veins of the Dolcoath mine.
G, granite; K, Killas or altered slate; E, Elvan (quartz porphyry) dikes. (Figures give feet.)

In recent decades the Australian tin veins have attained great importance, especially those in the New England district of New South Wales, and at Mt. Bischoff in Tasmania. As the ore from the latter locality comes mainly from residual gravels, we will discuss the Mt. Bischoff lodes in describing the tin placer deposits. Two other tin districts have recently been opened in Tasmania; the first is in the Blue Tier mountains in the northeast part of the island, where, as at Altenberg, the ore is obtained from tin-bearing greisen zones in the granite, holding from 0.375 to 1%

[1] Philips-Louis: 'Ore Deposits,' 1896. p. 601. R. A. F. Penrose: 'Tin Deposits of Malay Pen.,' *Journ. Geol.*, Vol. XI, 1903, pp. 135-154.

of tinstone.[1] The other area lies at Mt. Heemskirk near the west coast,[2] where quartz-tourmaline veins traverse a tourmaline-granite and the adjoining Silurian sandstones and slates. Along these veins the country rock has been hardened and impregnated with tourmaline and tinstone, exactly like that of Auersberg in Saxony.

In the United States, tin deposits are known in South Dakota, South Carolina (near Gaffney), and Texas. The first has already been described. The Gaffney deposit occurs in pegmatite dikes in sedimentary rocks changed to crystalline schists. The tin belt is 35 miles long, extending northward to Lincolnton, N. C. Similar deposits occur on Irish creek, near Roanoke, Virginia. The Texas deposits, as yet of no economic importance, are in the Franklin mountains, near El Paso. The veins are in a mass of intrusive granite that breaks through and uplifts Paleozoic limestones. The fissures are filled by quartz carrying cassiterite and wolframite and have greisen-like walls.[3]

As an African tin ore occurrence, we may mention that described by A. F. Molengraaff from Swazieland in the Transvaal.[4] An old schist is here broken through by granite masses surrounded by contact zones. Within the latter and in the granite itself, the occurrence of pegmatite veins has been noted, which at Embabaan, in the region of the Ryan tin works, have been found to contain corundum and tinstone. The pegmatite veins are 10 to 40 centimeters thick, consisting of quartz, with a lesser amount of feldspar, and carrying tinstone next to the walls in crystals which project toward the center of the lode.

Tin veins were discovered in 1903 in Seward peninsula, the most westerly portion of Alaska. The ores occur in wide dikes of rather fine-grained granite impregnated with fluorite.[5]

The youngest tin veins geologically are probably those of Mexico, which are associated with rhyolites and rhyolite tuffs. According to J. G. Aguilera,[6] besides cassiterite, they contain also specular hematite, topaz, sometimes tungsten, native bismuth and durangite ($Na[AlF]AsO_4$), but are without tourmaline. The most important deposits are near Aguascalientes, Durango, Guanajuato, San Luis Potosi and Zacatecas.

[1] W. H. Twelvetree: *Trans.* of the Austr. Assoc. for Adv. of Sc. Hobart, 1902, ref. *Zeit. f. Prak. Geol.*, 1902, p. 276.

[2] G. A. Waller: 'On the Tin Ore Deposits of Mt. Heemskirk.' *Rep.* to Secretary for Mines. A. 2236. Hobart, 1902.

[3] W. H. Weed: 'The El Paso. Texas, Tin Deposits,' *Bull.* 178, U. S. Geol. Survey, 1901. Also *Bull.* 213, pp. 99-102, 1903.

[4] A. F. Molengraaff: *Ann. Rep.* of State Geol. of S. Afr. Republic, 1897. 'The Mineral Industry,' Vol. XII, 1903, p. 332.

[5] A. J. Collier: *Bull.* 225, U. S. Geol. Survey, 1904, p. 221. See also *Bull.* 229.

[6] Mexican Volume *Trans.* Am. Inst. Min. Eng., 1903, p. 325.

VI. *Veins Showing Transitions Between Normal Tin Deposits and Other Classes.*

Examples of transitions from the purely tin-bearing deposits to copper deposits have been repeatedly mentioned, especially those of Cornwall. But there also exist transitions to the class of pyrite-blende-galena deposits. A. W. Stelzner and Schertel[1] were able to prove that the black zinc-blende of the Freiberg veins, in which a tin content had long been known, often encloses microliths of tinstone, and we know from older reports that tin ore was obtained even from Rammelsberg, and near Rosine[2] at Freiberg, in the gossan of the pyritic-zinciferous lead veins, so that the miners spoke of a tin gossan over silver-lead ore-lodes.

There is one example of the transition type between tin deposits and deposits of silver ores, upon which we have ample data, a type which is numerously represented on the high plateau of Bolivia between the 15th and 21st degrees south latitude. According to A. W. Stelzner,[3] this type includes the veins of the Cerro de Potosi (discovered in 1545), Ouro Colquiri, Poopo, Tasna, Milluni, Chorolque [highest mine on the earth, 5,309 m. (17,416 ft.) above the sea]. The gangue consists of quartz, with various carbonate spars and barite. The ore consists of sulphides and sulphates of iron, lead, zinc, copper, silver, tin, bismuth and antimony, but also includes tinstone. Silver and tin ores are so intimately mingled and intergrown that they cannot be separated by hand picking, and it is only after roasting and amalgamation that the tin can be obtained from the residue.

Besides cassiterite, the tin ores include stannite (tin pyrite), together with wolframite and, in places, tourmaline (*chorolque*) and fluorspar (*cloquirri*) also. An interesting fact is the presence of the two germanium-containing ores, argyrodite and franckeite.[4] In the upper workings the lodes were especially rich in tin, and it was only at greater depth that the tin ores were found rich in silver and lead. The cassiterite occurs especially in the form of wood tin and as hematite-like masses. In the Freiberg collection there is a lump of almost pure tin ore from that locality, weighing 93 kilograms. A secondary concentration of the tin content seems to have taken place in the outcrop. The silver occurring in the form of native silver and silver chloride and found in the astonishingly

[1] A. W. Stelzner and A. Schertel: 'Ueber den Zinngehalt der schwarzen Zinkblende von Freiberg.' *J.* f. d. B. u. H. im K. Sachsen, 1886.

[2] J. F. W. v. Charpentier: 'Mineral. Geographie der Chursächs.' 1778, p. 101.

[3] A. W. Stelzner: 'Die Silber-Zinnerzlagerstätten Bolivia.' *Z.* d. D. G. G. 1897, part 1. M. Frochot: 'L'étain en Bolivie.' *Ann. d. Mines* 90, XIX, pp. 186–222.

[4] A. W. Stelzner: 'Ueber Franckeit, ein neues Erz aus Bolivien,' *N. Jahrb.* f. Min., 1893, Vol. II, p. 114.

rich gossan, continued for centuries to maintain the reputation of Bolivia as the foremost silver-producing country of the globe. These Bolivian lodes are not associated with granite intrusions, but are, for the most part, connected with intrusive masses of dacite and rhyolite.

The tin exported from Bolivia in 1902 aggregated 16,779 tons, the product coming mainly from the departments of Potosi and Orouro. In the latter district the Huanuni mine alone produces every year 3,000 tons of tin ore.

VII. *Tungsten Deposits.*

In connection with the group of tin veins, we may here mention certain veins of tungsten, which, though devoid of tin, yet in their associations show altogether the same features as the tin lodes.

Thus Bodenbender[1] described veins in the southern part of the Sierra de Cordova in Argentina, which occur in granite and gneiss, and consist of quartz with wolframite, molybdenite, pyrite, chalcopyrite, covellite, limonite, apatite, mica, etc.

Tungsten veins are also known at several different points in North America, those occurring at Osceola, in the granite area of the Snake Mountains in Nevada,[2] containing besides wolframite a good deal of hübnerite.

In Portugal, veins of tungsten are exploited in the mines of Covelha (Castello Blanco), etc.

Another end product, or extreme example, of the type of deposit under discussion, which has been called the tin 'formation,' is represented by the pure fluorspar lodes, which, according to J. Valentin, are also worked in Argentina at San Roque in the province of Cordova.[3] The lode materials are fluorspar and quartz, with an occasional addition of red feldspar and a silvery white mica. Similar veins occur in Southern Illinois. According to Bain they are true fissure veins filled with fluorspar, calcite and scanty amounts of lead and zinc sulphides. The veins are 12 to 20 feet wide and cut Carboniferous limestones.

On the contrary, the fluorspar lodes of the Saxon Vogtland are more naturally classified with the copper deposits (which see), although they have some quite characteristic features, which they share in common with the tin veins.

[1] Bodenbender: 'Die Wolfram-Minen der Sierra von Cordoba.' *Zeit. f. Prak. Geol.*, 1894, p. 409.

[2] U. S. Geol. Survey, 'Mineral Resources for 1899-1900,' pp. 300-304.

[3] J. Valentin: 'Ueber das Flusspathvorkommen von La Roque,' etc. *Zeit. f. Prak. Geol.*, 1896, p. 104.

(b) DEPOSITS FORMED ESSENTIALLY OF SULPHIDE ORES.

(γ) Copper Veins.

5. Veins of Copper Ores Carrying Tourmaline; Including Also Veins Characteristic of the Tin Ore Types.

(*Tourmaline-bearing Copper Formations.*)

In discussing the characters of certain formations, mention was made of transition forms between the true tin veins and those of copper deposits, which were observed in many of the Cornwall and Saxon Erzgebirge veins, in which both tinstone and copper ores occur. Under the present head, however, we wish to include distinctively cupriferous veins, free from tin ore, which nevertheless contain, in both the ores and gangues, several minerals usually characteristic of tin lodes, veins which, like the tin deposits, are connected with granitic eruptions. This type, as J. H. L. Vogt correctly remarks,[1] represents, therefore, an extreme terminal member of the class of tin-copper veins already noted several times. For this reason this subdivision of the group of copper deposits has been placed immediately after the tin veins, heading the very important group of sulphide veins although it is not economically important enough to entitle it to that place when compared with the other types of copper veins, which are not only far more widely distributed, but are of very great economic importance.

The ores of this class of veins consist of chalcopyrite, bornite and copper glance, with accessory hematite, molybdenite, galena, zinc-blende, tetrahedrite, arsenic, bismuth and uranium ores and native gold, the gangue consisting of quartz, muscovite, calcspar, dolomite, siderite, fluorspar and tourmaline, as well as beryl and apatite.

As is the case with the tin lodes, the granite on both sides of these veins is strongly altered. The feldspar of the rock is destroyed and formed into quartz, mica and calcite. When altered to a typical greisen, it contains topaz and lepidolite.

This class of veins is especially represented in the Thelemark region in southern Norway, where it has been described by Th. Scheerer, T. Dahll, P. Herter and J. H. L. Vogt.[2] The lodes there outcrop either in granite, as at Klovereid, or in slate, near a granite massive as at the Aamdal copper works, or they form 'ladder' veins within the granite dikes that cut

[1] 'Zur Classification der Erzvorkommen,' *Zeit. f. Prak. Geol.*, 1895, p. 149.

[2] Th. Scheerer: 'Beiträge zur Kenntniss Norweg. Mineralien,' *Berg u. Hütten Zeit.*, 1845, p. 849 and 'Ueber die Kupfererz-Gangformation Thelemarkens,' *Berg u. Hütten Zeit.*, 1863, p. 157. Th. Dahll: 'Om Thelemarkens Geologi,' 1860. P. Herter: 'Ueber die Erzführung der Thelemarkischen Schiefer:' Z. d. D. G. G., 1871, p. 377, J. H. L. Vogt. *op. cit.*

quartzitic slate at the Näsmark mine, or as contact lodes along the borders of a granite dike, as in the Moberg mine. Bedded veins occurring between the planes of stratification of the slates have also been observed at the Aamdal copper works. On the contrary, the Svartdal lodes, in which the copper ores are associated with gold and tourmaline, are in a quartz-mica-diorite, not in granite, and this rock has, like the granite, been changed along the lodes into a greisen-like rock.

The Svartdal lodes show a close resemblance to the gold-bearing copper deposits described by A. von Groddeck, A. M. Stelzner and W. Möricke[1] in Chile, as at Remolinos and Ojancos in the province of Atacama, at Tamaya and La Higuera in the province of Coquimbo, and at Las Condes in the province of Santiago. The Chilean veins contain quartz and tourmaline, forming the matrix of the gold-bearing copper ores; the latter also contains some free gold, and rarely molybdenite and scheelite. They are usually associated with acid or moderately acid eruptive rocks, which in some instances have undergone tourmalinization along the lodes. The copper production of Chile in 1903 amounted to 31,330 tons, which, however, includes the product of other types of deposits.

6. Cupriferous Quartz Veins.

Chalcopyrite, chalcocite, bornite, enargite and tetrahedrite occur in veins with quartz filling. Pyrite often occurs in the chalcopyrite.

The most instructive European example of this type is probably the Kupferberg district in Silesia, of which we have a detailed description by Websky.[2] The veins outcrop in a hornblende schist and other crystalline schists, which form a zone between the Paleozoic grits of Landshut and a granite massif, and are traversed by dikes of porphyry. The vein filling consists of quartz and hornstone; the ores occur in bunches and pockets, and consist of copper glance, bornite, chalcopyrite, pyrite, pyrrhotite and zinc-blende, and in druses, of tetrahedrite. In rare cases a flesh-red feldspar is also said to be a constituent, and, finally, in some cases, cobalt and nickel ores. For the most part the deposits are true fissure veins with a good deal of enclosed country rock. Krusch divides the deposits into three classes, viz.: (1) Older veins, with quartz, calcite, gypsum, fluorite, chal-

[1] A. v. Groddeck: 'Ueber Turmalin enthaltende Kupfererze von Tamaya.' *Zeit.* d. D. G. G., 1887. A. W. Stelzner: 'Ueber die Turmalin-führung der Kupfererzgänge in Chile.' *Zeit. f. Prak. Geol.*, 1897, p. 41. W. Möricke: 'Die Gold,- Silber, und Kupfererlagerstätten in Chile.' 1897.

[2] Websky: 'Ueber die geognost. Verh. d. Erzlagerstätten von Kupferberg und Rudelstadt in Schlesien.' Z. d. Deutsch. geol. Ges., Vol. V., 1853, pp. 373–438. P. Krusch: 'Die Classification der Erzlagerstätten von Kupferberg in Schlesien.' *Zeit. f. Prak. Geol.*, 1901, pp. 226–229.

copyrite and some galena, together with chloritized country rock. (2) Younger, pure quartz veins, with disseminated chalcopyrite. (3) Ore beds like those of Schwarzenberg, with a floor of actinolite, prase and chlorite, much pyrite and accessory pyrrhotite, chalcopyrite and bornite, with lievrite and magnetite (Einigkeit vein).

A similar deposit described by A. von Groddeck[1] occurs at Rheinbreitenbach on the Rhine, in the Devonian graywacke area.

In the kingdom of Saxony this class of copper veins is found in the Schneeberg mining district, particularly at the old mines of König David and Sanct Michaelis near Oberschlema.[2]

Many of the veins of the Massa Marittima district of Tuscany belong to this quartz-copper vein type, as shown by Lotti[3]; as, for example, the Boccheggiano vein, while others, viz., the Fenice Massetana, Capanne Vecchie, Serrabottini, Sud and Guardione veins also carry blende and galena, and thus form transitions to the pyrite-blende-lead veins.

These deposits also show great variety of form, for besides the true veins just mentioned, irregular stock-like bodies occur, as a result of the replacement of lime rocks along the bedding planes separating dissimilar strata or along faults. Thus, at the plane of separation between the dolomitic Rhaetic limestones and the alternating beds of shale and limestone of the Eocene, there are ore deposits, as, for example, the iron and calamine deposits of Carbonais (Valdaspra), the copper, lead and calamine deposits of Rocchette and Serrabottini-Nord, as well as those of the Speziala, and the copper and iron ore deposits of Cagnano-Pighetti. The lead ore deposits of Montieri and Gerfalco are associated with Liassic limestones.

The veins occupy fault lines, along which the country rock has been much altered. This alteration has produced either silicification with the deposition of copper and iron pyrite and in part a segregation of epidote or else a complete metamorphism into a pyroxene-epidote rock. In some cases (Guardione) this alteration and replacement extends much farther into the hanging-wall than into the footwall. All the veins are of post-Eocene age.

The vein worked at Boccheggiano, an important mining town, northeast of Massa Marittima, is worthy of special mention. The course of the vein is north-northeast, the dip 40 to 50° northeast. The vein has a thickness of 30 m. to 33 m. (98 ft. to 114 ft.) and is mined for 1,200 m. across the Merse valley, being worked on both sides of the stream. It occupies a fault

[1] A. V. Groddeck: 'Erzlagerstatten,' 1879, p. 202.

[2] H. Müller: 'Die Erzdistrict von Schneeberg im Erzgebirge.' 1860. Cotta's *Gangst.*, III, p. 70.

[3] B. Lotti: 'Descrizione Geologico-Mineraria dei Dintorni di Massa Marittima. Rome, 1893. (Gives other references.)

with micaceous shales of Permian age beneath, and the Eocene limestones and clay shales above. Segregations of epidote occur along cross fissures as far as 50 meters from the vein. The ore consists of quartz, containing pyrite and copper pyrite, with scanty amounts of marcasite, bismuthinite and hematite. The workable ore occurs in three column-shaped shoots pitching northward. The rich ores show, in part, a massive and, in part, a banded structure. Large pyrite cubes occur sparsely interspersed through the ore. In places the vein filling consists of a mineralized slate breccia. The ore contains 3 to 11% of copper, with various other metals, including 0.04% of tin. The gangue is chiefly quartz.

A spring tapped at the lowest part of the shaft, with a temperature of 40.6° C., is at present greatly interfering with the work.

Some of the more important occurrences of other continents should also be noted:

Among these is the copper vein of the Chudak mine in the Altai, 6-7 m. thick, outcropping in the quartz porphyry.[1]

Splendid examples of this type of vein occur in diabase at the Sünik mine, near Kata, south of Schuska, in the Transcaucasia.[2]

Australian Deposits.

Many of the copper veins of Australia are quartz-pyrite veins. The Burra-Burra mines of South Australia, since their discovery in 1845, in the space of 29.5 years, have yielded 234,648 tons of copper ore, with an average content of 22% copper, corresponding to 51,622 tons of copper. Work ceased in 1877, as the two main lodes were worked out. The vein lies on a contact between 'serpentinous' limestone[3] and steeply upturned, thinly bedded limestones. Subsequently the lodes of Wallaroo, in porphyrite and Moonta,[4] also in porphyrite, were discovered, which are also exceedingly large (30 feet) and average 12% copper. The two together produced in 1897 about 5,100 tons of copper.

The Great Cobar copper mines in New South Wales, which recently regained their former importance, work quartz veins in the Silurian slates. The main ledge is in its upper level, 25 to 45 feet wide and composed of nearly solid sulphides. The total copper production of Australasia in 1902 was 29,098 tons.

African Veins.

The most noteworthy African examples are the veins in metamorphic

[1] B. von Cotta: 'Kupfergrube Tschudack im Altai.' *Berg u. Hütten Zeit.*, Vol. XXIX, 1870, No. 7, p. 29.

[2] K. Ermisch: 'Die Kupfererze der Sünikgruben', *Zeit. f. Prak. Geol.*, 1902, p. 88.

[3] J. D. Woods: 'The Province of South Australia.' 1894, p. 258.

[4] Phillips-Louis: 'Ore Deposits.' 1896, pp. 691–693.

Devonian slate and granite in Little Namaqualand and Demaraland and on the west coast of South Africa, from which in 1898 the production was 2,438 tons of copper. This class also includes the veins of the Albert silver mine, 50 miles northeast of Pretoria in the Transvaal. These veins outcrop in an area of reddish porphyritic granite traversed by dikes of olivine diabase. The primary vein consists of quartz with bornite, chalcopyrite, silver-bearing tetrahedrite and some hematite (Freiberg collection).

Japan.

The most productive copper veins of Japan, those of Ashio, belong to this group. These lie near Nikko, so famous for its shrines and temples (province of Shimodzuke). According to Yamada (statement in a letter) the Paleozoic (pre-Carboniferous) sandstones, clay slates and hornstones of that locality are traversed by a stock of rhyolite. This rhyolite, which grades at times into dacite, has altered the sedimentary rocks along the contact and encloses many fragments of them. In the rhyolite, but not in the contact rocks, there are numerous northeast or west-northwest to east-west veins dipping steeply north or south. These veins consist mainly of copper pyrite, pyrite, arsenopyrite and quartz. Their walls are usually sharply defined, but sometimes only on one side. Besides the typical copper veins, there are also pyrite-blendic lead veins at Ashio, though these are much rarer. The production of the Ashio mines in 1902 was 6,762 tons of copper. The total Japanese production in 1903 was 31,360 tons of copper.[1]

Butte, Montana.[2]

The prodigious production of the veins of this kind at Butte City, Montana, in recent years, has surpassed that of any other district of the world.

The Butte district is situated in southwestern Montana, in the central part of the Rocky Mountain region. The city, which is built about and over the mines, is the largest settlement of the State, while the neighbor-

[1] Sketch of the Mining Industry of Japan. Published by the Bureau of Mines of Japan for the Louisiana Purchase Exposition, 1903.

[2] W. H. Weed: 'Ore Deposits at Butte, Montana,' *Bull.* 213, U. S. Geol. Survey, 1903, p. 170. S. F. Emmons: 'Notes on the Geology of Butte, Montana.' *Trans.* Amer. Inst. Min. Eng., Vol. XVI, 1887, p. 49. Jas. Douglas: 'The Copper Resources of the United States.' *Trans.* Amer. Inst. Min. Eng., Vol. XIX, 1891, p. 693. R. Vogelsang: 'Ueber den Kupferbergbau in Nordamerika.' *Z.* f. d. B. H. u. S. im preuss. St., 1891, Vol. XXXIX, p. 248. C. A. Hering: 'Die Kupfererzlagerstätten der Erde.' *Idem*, 1897, pp. 19–22. S. F. Emmons: 'Economic Geology of the Butte District.' Geol. Atlas of the U. S., Butte, Montana, folio, 1897. W. H. Weed: 'The Secondary Enrichment of Ore Deposits.' *Bull.* Geol. Soc. Am., Vol. XI, pp. 179-206, 1899-1900. R. C. Brown: 'The Ore Deposits of Butte City.' *Trans.* Am. Inst. Min. Eng., Vol. XXIV, 1895, p. 556.

ing city of Anaconda, 20 miles distant, is a dependent. The rocks of the ore-bearing area are all igneous, the district forming part of an extensive region of Tertiary igneous activity. The prevailing rock, and the one in which all the veins occur, is a dark basic granite, technically known as quartz-monzonite, which is a part of a great mass of granitic rock. This rock is cut by dikes and irregular intrusions of the Bluebird granite, a white aplite[1] composed of quartz and feldspar, with a little mica. In the copper-bearing area the Modoc porphyry appears in lenticular dikes, traversing both varieties of granite in very irregular fissures. It is a light-colored rock, carrying large and distinct crystals of feldspar and quartz in a dense groundmass, and is technically designated rhyolite-porphyry or quartz-porphyry.

After the intrusion of the Modoc porphyry, extensive fracturing occurred, with vein formation, the veins cutting the porphyry in many instances. After the formation of these earlier veins they were fractured, and silver veins formed, followed by renewed volcanic activity, resulting in the intrusion and eruption of rhyolite, forming dikes cutting across the veins, and in extensive extrusive masses covering the silver veins to the west. The veins of the district, both copper and silver veins, belong to four distinct systems. The oldest lodes have a general east-west course, the Parrot, Anaconda and Syndicate lodes being examples. Another set of veins has a northwest-southeast course, and has displaced the earlier veins. A still later set has an east-northeast course and has displaced both the earlier systems of veins. These veins, in the eastern part of the area, are cut and displaced by a great northeast fault which carries no endogenous ore, the material mined having been broken off from earlier deposits and included in the fault débris.

The silver veins surround the copper lodes on the north, west and southwest. Their course and geologic relations are very similar to those of the copper veins, but their structure and mineralogic character are different. The silver veins contain sulphide of silver, blende, pyrite and a little galena, and commonly contain no copper, save near the border of the copper area, where, though occasional bunches of copper ore occur, it consists of chalcopyrite, and, more rarely still, tetrahedrite, minerals which occur rarely and very sparingly in the copper lodes. The gangue consists of quartz, with rhodonite and rhodochrosite, and shows marked banding and crustification, in strong contrast to the structure of the copper veins.

Several of the copper veins were, as is well known, at first worked as silver veins. The upper portion of the veins consisted of quartz somewhat stained by iron, but not like the great iron gossan caps of other regions.

[1] Called 'granulite' by some writers—a name applied by German geologists to a variety of schist, but by French petrographers to aplite.

This extends to a variable distance below the surface, 200 to 400 feet in some instances, where it is replaced by partly oxidized and decomposed copper ores that form the upper limit of the remarkable glance, enargite and bornite orebodies of the district. Carbonates and oxides are rare.

The copper minerals occur in quartz-pyrite veins of remarkable width and extent. The Anaconda ledge is sometimes 100 feet wide, and will average half that width, as will also the Syndicate lode.

Character of the Ores.—The copper ores average 55% silica and 16% iron. About 15% of the tonnage mined is first-class ore, averaging 12% copper; the remaining 85% carries 4.8% copper, and is treated in concentrating mills, the resulting product containing but 15 to 20% of silica, while the copper is increased to 18%.

The ores contain gold to the extent of about 2.25 cents to each pound of copper, with 0.0375 ounce of silver. Native gold has been found upon crystallized glance, and native silver is common in bornite and glance in some mines. It is estimated that the total production of copper ore has been about 31,000,000 tons, averaging 5% copper. The amount of arsenic (and antimony) present is very large, it being estimated that over 32,000 lb. a year pass off in smelter fumes. Tellurium is present in very small quantity in the ores, amounting to 2.375 ounces, or 0.008%, in the crude copper from the converters.

In general, it may be stated that the original mineral-bearing solutions were in all probability hot and ascended through fractures in the granite. The copper deposits are almost entirely replacement deposits. There is a marked association of faulting of the veins with bodies of rich ore, and these faulted areas are wet, so that the miners say: "A dry and tight vein is barren; a wet and crushed one is rich." There is also a distinct genetic relation between ore and country rock, as a result of the deposition of the ore by metasomatic replacement. Thus the Anaconda ledge is low grade where it crosses either the Bluebird granite or the Modoc porphyry, a feature explainable by the lack of easily replaceable, dark-colored, ferromagnesian minerals in those rocks.[1]

In 1903 Montana produced 272,555,854 lb. of copper. The Anaconda mine alone yielded between 1879-1897 about 470,000 tons of copper.

Cupriferous quartz veins also occur in the Virgilina district along the border between Virginia and North Carolina, but the annual production does not exceed 3,000 tons. The copper occurs as glance and chalcopyrite, more rarely as bornite, in bunches and stringers sparingly distributed through the massive quartz filling of the veins. In the Blue Wing mine the

[1] W. H. Weed: 'Influence of Country Rock,' etc., *Trans.* Amer. Inst. Min. Eng., Vol. XXXI, p. 634, 1901. Also *Amer. Geol.*, Vol. XXX, p. 170, 1902.

vein filling is calcite and the ore bornite. These veins are traceable for several miles by well defined outcrops. They cut soft micaceous schists formed by the metamorphism of pre-Cambrian andesites and volcanic tuffs.[1]

The type of copper quartz veins just described is connected by various gradations with the pyrite blende bearing lead deposits. Several veins in the Freiberg area, proper, belong to such a transitional type. The quartz gangue contains copper pyrite, bornite, copper glance and gray copper, and in the upper portions oxidized ores, Galena, zinc-blende, arsenopyrite and pyrite occur in lesser amounts. As examples the Gottlob Spat, Franzer Spat and Heinricher Spat at Morgenstern may be mentioned. This was also the character of the now abandoned veins of Junge Höhe Birke and Alte Mordgrube, at least of certain parts of the veins, as, for example, the steep-dipping layers of the Alte Mordgrube.

Veins of intermediate type also occur at Hohenstein[2] in Saxony. They consist of pyrite, arsenopyrite, chalcopyrite and tetrahedrite, in quartz, brown spar and calcite, with some marcasite, galena, zinc-blende and bournonite. These veins are remarkable for their gold content. They are typical copper veins in certain parts of the lode. The two copper minerals named above are carriers of the silver and gold content, the gray copper containing about 0.01% of gold. The Lampertus mine is still in operation.

Similar transitional types are found in other countries; for example, some of the lodes of Sado and Ikuno in the province of Tashima, in Japan, are, according to Yamada, of this nature.

As an appendix to this last group, we may mention the remarkable manganiferous copper lodes, forming a transition of purely manganese veins, found in the vicinity of Muleye in lower California. Their mineralogy has been studied by P. Krusch.[3] They outcrop in Tertiary trachytic tuffs about 110 kilometers north-northwest of the town. In the undecomposed state they carry a manganiferous and cobaltiferous copper glance with gangue of chalcedony with associated gypsum. Farther east there are also found true maganese lodes, with quartz and gypsum as matrix and a psilomelane containing 0.38 to 1.2% copper.

7. Spathic Copper Veins (Gangue of Various Carbonates with Quartz, Barite and Sometimes Fluorspar).

The gangue of these veins includes some quartz, but often consists chiefly, and sometimes entirely, of various carbonates, particularly iron spar, as well

[1] W. H. Weed: 'Types of Copper Deposits in Southern United States.' *Trans.* Am. Inst. Min. Eng., 1900.

[2] H. Müller: 'Ueber die Erzgänge von Hohenstein,' 1879, in Erläut. zu Sect. Hohenstein., p. 28 *et seq.*

[3] P. Krusch: 'Ueber manganhaltige Kupfererzgänge.' *Zeit. f. Prak. Geol.*, 1899, p. 83

as calcspar and dolomite. Barite is very common and is at times accompanied by fluorspar. The ore minerals are chalcopyrite, bornite, glance, tetrahedrite and pyrite. Cobalt and nickel ores and various other ores also occur as accessory minerals.

The lodes of Kamsdorf, near Saalfeld, in Thüringia, have been studied and described by F. Beyschlag.[1] The veins fill fault fissures in the *zechstein* (Permian limestone) formation, and they also continue downward as barren siderite-barite veins, into the strongly folded and tilted Culm slates underlying the *zechstein* formation. In these lodes, barite is the chief vein mineral, carbonates appearing but scantily, and quartz only showing where the fissure is within the Culm. Among the ores an argentiferous gray copper and a non-silver-bearing copper pyrite, together with secondary copper ores, are most common; cobalt and nickel ores are accessory constituents, especially smaltite (cobalt pyrite) and niccolite (NiAs). The ores often enclose fragments of the country rock. The structure is both massive and brecciated, and it is only where the lodes descend into the Culm that a symmetric banding of the lode is seen. The veins are richest between the dislocated parts of the bed of Kupfershiefer faulted by the veins. In the upper strata as well as in the Culm the lodes are barren of ore. Near the veins certain beds of the lower and middle *zechstein*, especially limestone and dolomite strata, are replaced for varying distances by spathic iron ore. The veins are now worked for these masses of spathic iron ore, or the secondary brown hematite derived from them. The orebodies at times contain impregnations of copper ore. The diagrammatic section (Fig. 153) is a composite made from several of Beyschlag's profiles. The total product of the Kamsdorf mines for 1898 was 24,760 tons of spathic iron ore and 17,929 tons of brown hematite.

Near Ceilsdorf and Oelsnitz, in the Vogtland of Saxony, similar veins cut Devonian rocks, not the *zechstein*. Analogous veins were worked at the beginning of the 19th century, at the mines of Deichselberg. The mines of Sanct Burkhard and Heilige Dreifaltigkeit (Holy Trinity) were formerly important. Some of the lodes, it is true, are worked mainly for spathic iron ore; in fact, transitions to the non-copper-bearing spathic iron ore lodes may be very frequently observed in this class of copper veins.

Some of the copper veins of Vogtland vary in character, containing a large amount of fluorspar, being, in fact, worked only for this mineral to-day. The Auf der Kunst vein, which is in places over 25 meters thick, is a typical example of this kind. It lies between Schönbrunn and Planzschwitz in the Saxon Vogtland and belongs to the Heilige Dreifaltigkeit

[1] F. Beyschlag: 'Die Erzlagerstätten von Kamsdorf in Thüringen.' *Jahrb.* d. k. preuss. geol. Landesanst., 1888, p. 329.

mine just noted. According to E. Weise,[1] this vein occupies a fault fissure dipping steeply east-northeast and striking north 25° west, cutting Devonian slates, diabase breccias and diabases. The footwall streak carries brown hematite (altered spathic iron ore) and copper ores. Above this lies a thick streak of quartz, carrying fluorspar, brown hematite and subordinate copper ores. The middle band, 2 to 8 meters thick, is formed of white and

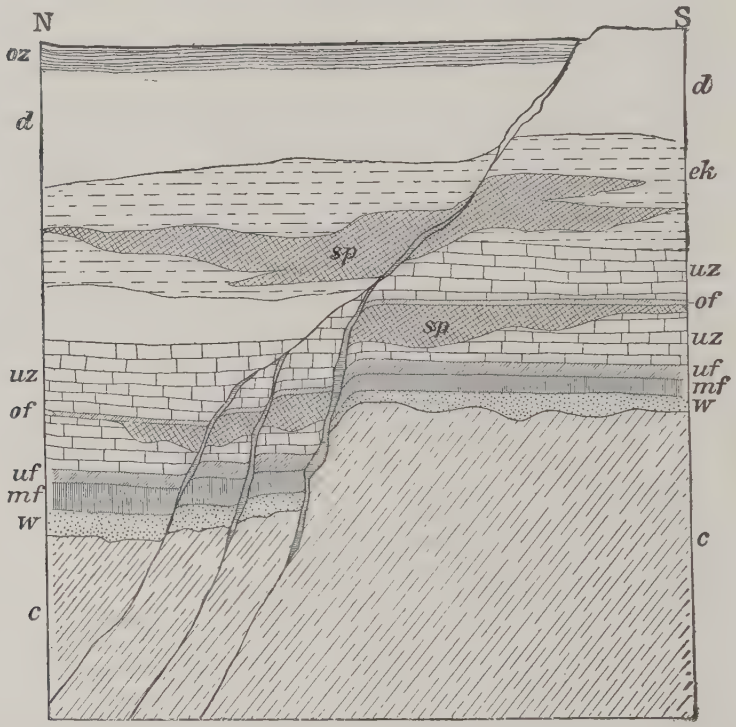


Fig. 152*a*.—Ideal cross-section through a mineral vein at Kamsdorf. (F. Beyschlag.)
oz, upper zechstein slates; d, dolomite; ek, ferriferous limestone; sp, brown hematite and spathic iron ore; uz, lower zechstein limestone; of, upper bed; uf, lower slate bed (copper slate bed); mf, mother bed; w, zechstein conglomerate; c, Culm schist.

green fluorspar. In the uppermost layer lenticular bodies of copper ore with barite and violet fluorspar occasionally occur imbedded in the barite.

A similar vein is worked at the Brüder Einigkeit mine at Bösenbrunn, near Oelsnitz.

[1] E. Weise: 'Erläut zu Section Plauen-Oelsnitz' der geol. Spezialk. v. Sachsen, 1887, p. 74.

It may be well to point out that this somewhat aberrant development of the spathic copper deposits agrees in many respects with that of the tourmaline-copper veins, and thus approaches the tin deposits in character, a relationship which does not obtain in the case of the typical examples of Kamsdorf. As a matter of fact, tin ore was obtained between 1511 and 1533 from the Vogtland region, where these fluorspar-bearing lodes occur, and even from the Sanct Burkhard and Heilige Dreifaltigkeit, now referred to as copper mines.

The numerous barytic copper veins of the Rhine valley are of purely scientific interest. They occur in the Black Forest, the Odenwald and at Spessart. These deposits are, according to K. von Kraatz-Koschlau,[1] partly of pre-Triassic age, in part of Tertiary age. They strike northwest, rarely east-west. Their filling consists of barite of two generations, fluorspar, hornstone, chalcedony, quartz, copper pyrite and pyrite, as well as oxidized copper ores.

Among the copper deposits in the Alps this class is represented by a vein, 2 to 3 meters thick, outcropping in the Silurian clay slate of Mitterberg near Werfen in the Salzburg district. The vein filling consists of quartz, siderite, ankerite, copper pyrite and iron pyrite. F. M. Stapff[2] points out the fact that in this lode both copper pyrite and spathic iron tend to form lenticular masses in the quartz, and these ore shoots are at times inclined at an oblique angle to the walls. Sometimes the ores contain intergrown leaves of hematite.

A quartzose variation of this type of vein appears among the copper veins recently described and graphically represented by C. Derler,[3] veins which cut the Silurian clay slates in the vicinity of Kitzbühel in the Tyrol. They were formerly worked at Röhrerbühel and Sinwell, and even to-day some mines are still worked at Schattberg, in the Kupferplatte and on the Kelchalpe. The fissures, which attain a width up to 4 m. (13.1 ft.), are filled with quartz, some ankerite, fragments of slate and copper pyrite, and at times contain also pyrite, gray copper ore, niccolite, chloanthite ($NiAs_2$), zincblende and galena. The chalcopyrite occurs in scattered grains, small streaks, and as occasional large masses of compact ore within the vein filling.

A typical development of this form of lode is found at Altgebirg and Herrengrund, north of Neuschl, in northern Hungary. Quartz, barite, siderite, brown spar, copper pyrite and gray copper form the fissure filling of the

[1] K. v. Kraatz-Koschlau: *Abh.* d. Hess. Landesanst, 1897, Vol. III, part 2, p. 55.

[2] F. M. Stapff: 'Geognost. Notizen über einige alpine Kupfererzlagerstätten.' *Berg u. Hutten. Zeit.*, 1865 p. 6.

[3] 'Bilder von den Kupferkies-Lagerstätten bei Kitzbühel.' Vienna, 1890. Published by J. Graf. Falkenhayn.

Pfeifer vein, which traverses the mica schist, while the Kugler vein runs parallel to the stratification of the Triassic greywacke schist.[1] Similar lodes at Kotterbach, Szlovinka and Göllnitz in the Gömör-Zips schist area contain, besides the minerals mentioned, also some cinnabar.[2]

In the Swiss Alps the lodes of Mürtschenalp, in the canton of Glarus,[3] described by G. Troger and E. Stohr, outcrop in the Sernf conglomerate rock. They are probably of Permian age, and contain besides the copper ores (mainly bornite) also some pyrite, gray copper, hematite and molybdenite, the matrix being finely crystalline dolomite.

This type of vein also occurs in the Japanese copper districts. In the northern and central part of the main island there are five examples, viz.: Osaru-zawa, in the province of Rikutschu, Arakawa and Ani in the province of Ugo, Kusakura in the province of Etachigo, and Ogoya in the province of Kaga. According to a letter from Mr. Yamada, the strata of the Tertiary formation are there everywhere traversed by rhyolites and partly by propylitized andesites. The veins occur in the eruptive rocks. They consist of copper and iron pyrite, with lesser amounts of specularite and lead, zinc and silver ores in a gangue of quartz, calcspar, rhodochrosite and barite. In the Kusakura mine the specularite content increases considerably in depth. Similar veins occur in Paleozoic beds at Yoshioka in the province of Bitshu, and at Sassagatani and Dogamaru, in the province of Iwami, district of Chugoku. They are said to be connected with the granite and diorite intrusions of that locality.

8. Zeolitic Copper Veins with Native Copper.

This type of copper vein is quite uncommon, but, with the mineralogically similar amygdaloid beds and copper-bearing conglomerates, forms the enormously productive deposits of the Lake Superior region. The veins, formerly the exclusive source of copper, are no longer worked. Native copper and some native silver occur, accompanied by calcspar, laumontite, prehnite, apophyllite, natrolite, datolite, desmine, quartz, fluorspar, epidote and chlorite.

A brief description of the entire copper ore district of Lake Superior is given because these veins form a genetically connected whole with the other copper deposits of the locality.

[1] B. v. Cotta: *Erzlagerstatten.* II, p. 304.

[2] G. Faller: 'Reisenotizen' in *Berg- u. H.-Jahrb.* d. k. k. Bergak, 1867, Vol. XVII, p. 132.

[3] G. Tröger: 'Ueber den Kupfer- und Silberbergbau an der Mürtschenalp.' *Berg u. H. Z.*, 1860, p. 305. E. Stöhr: 'Die Kupfererze an der Mürtschenalp.' Zürich, 1865.

The copper region of Lake Superior[1] lies on a long peninsula projecting into Lake Superior and terminating in Keweenaw Point, the copper belt being 130 miles long and 6 miles wide. The eastern side of the peninsula is formed of Cambrian (Potsdam) sandstone, the west side of vast sheets of melaphyre (Irving's diabase) and melaphyre-amygdaloid, with intercalated beds of conglomerate. The age of the melaphyres, which in part bear all the characters of old lava streams, has been much disputed. According to M. E. Wadsworth the copper-bearing strata

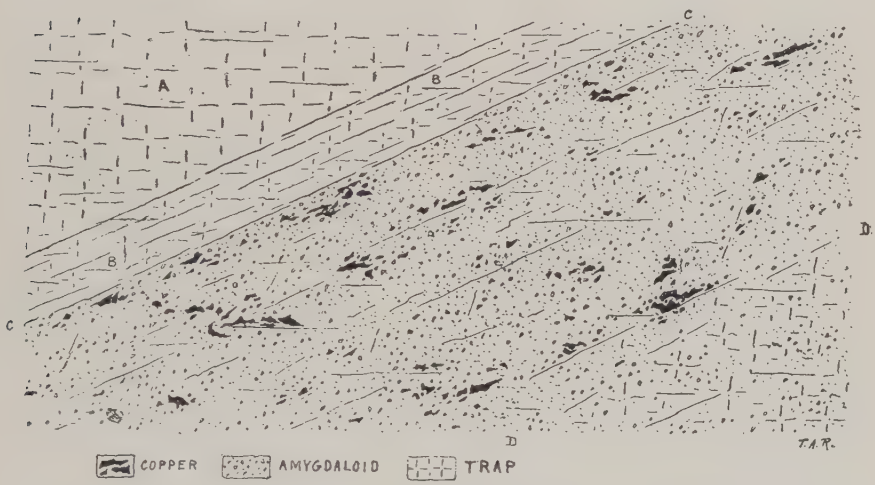


Fig. 152*a*.—The Quincy (amygdaloid) lode. (T. A. Rickard.)

rest on the Cambrian sandstones; according to R. D. Irving and T. C. Chamberlin this overplacement is merely apparent, in consequence of an over-thrust along a plane of dislocation, which in certain portions can be identified with certainty. The amygdaloidal structure of the eruptive sheets has been especially developed in the parts near the surface, while

[1] The following list comprises the most important publications upon this district: Herm. Credner: 'Beschreibung einiger charakteristischer Vorkommen des gediegenen Kupfers auf Keweenaw Point,' etc. *N. Jahrb.* f. Min., 1869, pp. 1–14. R. Pumpelly: 'The Paragenesis and Derivation of Copper and Its Associates on Lake Superior.' *Amer. Journ. Sc.*, 1871 (3), pp. 188 *et seq.* and 'Geol. Surv. of Michigan,' Vol. I, pt. II. 'Copper Bearing Rocks,' 1873. 'The Metasomatic Development of the Copper-Bearing Rocks of Lake Superior,' *Proc.* Amer. Acad. of Arts and Sc., Vol. XIII, 1877–78, p. 253. E. Wadsworth: 'Notes on the Geology of the Iron and Copper Districts of Lake Superior.' Cambridge, 1881. R. D. Irving: 'The Copper-Bearing Rocks of Lake Superior.' Washington. *Monograph*, U. S. Geol. Surv., 1883. T. C. Chamberlin: 'The Copper-Bearing Series of Lake Superior,' Cambridge, 1883. T. A. Rickard: 'Copper Mines of Lake Superior,' *The Engineering and Mining Journal*, 1904, Vol. LXXVIII, No. 15 *et seq.*

the deeper parts show a diabasic structure. On Keweenaw peninsula, the largest and most famous mine is the Calumet & Hecla, one of whose vertical shafts is 4,920 feet deep; the Portage, Osceola, Quincy, Central mines, where the largest masses of native copper were found, and the Copper Falls and Cliff mines are well-known producers. The copper area extends along the south shore of the lake southwestward, where the Minesota mine, in the vicinity of Ontonagon, is especially noteworthy. In this direction the copper-bearing series may be followed into Wisconsin, but no workable deposits are known. On Isle Royale, near the Canadian shore, deposits of similar character were worked.

Following H. Credner, three different kinds of deposits may be distinguished within the copper-bearing rock group:

Disseminated Grains and Amygdules in the Melaphyre Lava Sheets.

Such copper-bearing lavas, called amygdaloids and 'ash beds,' are worked in the Quincy, Franklin, Osceola, Atlantic, Huron and Copper Falls mines. At times the vesicular cavities of the amygdaloids are exclusively filled with native copper, sometimes accompanied by native silver, calcspar, quartz, chlorite, laumontite, prehnite, analcite, epidote, datolite, hematite, etc. The two native metals often occur intergrown into one lump, and hence cannot have been congealed from the molten condition as a magmatic segregation, for in that case they would have formed an alloy. On the contrary, like the constituents of the accompanying zeolites, they seem to have been leached out of the melaphyre itself, in which they may have existed at one time in fine particles of sulphides, subsequently concentrated by secondary process in the existing cavities.

In the Conglomerates.

The conglomerates, according to Wadsworth, are characteristic littoral formations. Their pebbles consist of quartz porphyry and melaphyre, and are often quite decomposed and disintegrated, and this material has been replaced and impregnated with copper. The interspaces between the pebbles are largely filled by native copper, with the same associated minerals as in the amygdaloid. Such conglomerates are worked at the Calumet & Hecla mine.

Filling of True Fissures.

The thickness of these veins is usually 1 to 3 m. (3.3 to 10 ft.), but sometimes rises to 10 m. (33 ft.) The more decomposed and porous the country

rock, the richer the ore; the fissures accordingly carry their best orebodies at the points where they traverse the amygdaloids. The great thicknesses given for some veins include the adjacent country rock, which, when strongly impregnated with copper, has been counted as included in the vein proper; occasionally vein stringers group themselves into stock-like aggregates. The fissure filling consists of quartz, calcspar, prehnite, laumontite, apophyllite, natrolite, stilbite, as well as epidote, chlorite and fluorspar, native copper and some native silver. Fragments of the decomposed country rock are always found in the fissures. The sketch by Credner (Fig. 153) gives a typical cross-section of such a vein. The native copper forms jagged and stout branched lumps, sometimes of astonishingly stout dimensions and

Fig. 153.—Cross-section through Cliff lode. (H. Credner.)
m, amygdaloid; c, calcite; l, laumontite; k, copper; q and p, quartz and prehnite with copper; e, epidote; a, apophyllite.

weighing several thousand kilograms. Mining is now confined to the conglomerate and amygdaloid beds.

Genetically these deposits are best explicable by the assumption of a lateral secretion of the copper ores, which were originally finely distributed in the melaphyres. The only enigma is, why the re-secretion and concentration took the form of native copper. According to Pumpelly, and, later, Van Hise, the copper is reduced from solution by magnetite and iron oxide.

The copper mines of Lake Superior for a long time took the lead in the copper production of the world. The Calumet & Hecla alone yielded 555,000 tons of copper in 1867-1897, all the other works on Lake Superior from 1845-1897 about 440,000 tons. The mines have been carried to astonishing depths; Red Jacket shaft of Calumet & Hecla has attained 1,460 m. (4,920 ft.). At the present day the "Lake Mines" occupy the second place in the world's production, being surpassed only by the mines in Montana.

In 1903 the total production of the works on Lake Superior was 192,400,577 pounds of copper, of which Calumet & Hecla alone produced 76,620,145 pounds, or about 6 per cent. of the world's entire supply of copper.

Copper-bearing amygdaloid melaphyres also occur in the district of Dschida in the Trans-Baikal, carrying native copper associated with opal, chalcedony, calcite, epidote and prehnite.

Native copper accompanied by native silver occurs[1] in diabase porphyries in the Mercedes mine, near Algodones, Chile. The eruptive rock shows propylitic alteration, and holds small amygdules of calcite, an undetermined green decomposition product, native copper and cuprite. Möricke cites

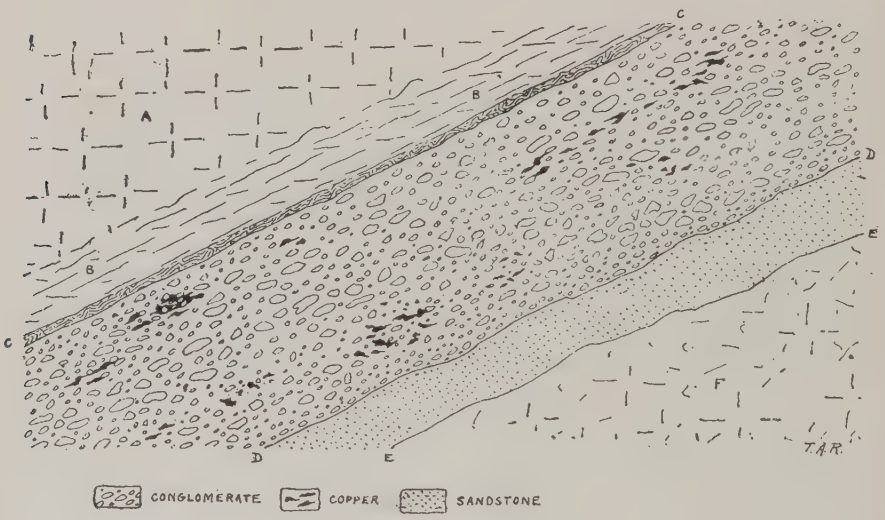


Fig. 153*a*.—The Franklin, Jr. (conglomerate) lode. (T. A. Rickard.)

the Queensland deposits described by Daintree as analogous in character. The latter contain native copper and copper sulphides, with malachite, calcite and prehnite in amygdaloidal dolorites. Native copper is also found with zeolites in basalt in the Faroe Islands.

An interesting occurrence of native copper in feldspathic segregations of the gabbro of Pari, in Tuscany, is described by Lotti.[2]

The deposits at Zwickau, Saxony, seem to be genetically analogous, though not of economic importance, native copper occurring in quartz porphyry and porphyry tuff. These rocks form intercalations in the middle Rothliegende close to an underlying sheet of melaphyre. The copper is

[1] W. Möricke: 'Die Gold, Silver und Kupferlagerstätten in Chile.' Freiberg, Baden, 1898, p. 33.

[2] B. Lotti: *Zeit. f. Prak. Geol.*, 1899, p. 354.

found in thin sheets (rarely as much as 3 m. thick, up to 0.5 m. long and 0.15 m. broad) which usually fill short fissures, that rapidly wedge out on both sides; more rarely it is found in larger fissures which may be connected with fault planes. On both sides of the fissures, in zones 0.5 to 2 cm. wide, the dirty violet colored rock is leached and altered to yellowish white. This is supposedly due to reducing solutions. Spherical reduction spots are also found in the midst of the unfissured porphyry mass, and in the center of these spots native copper was also found at times in grains. Besides the native copper, A. Weisbach[1] discovered domeykite (mohawkite) (Cu_3As) in the quartz porphyry. Especially rich masses of copper ore were found in sinking several coal mine shafts, showing a rather wide horizontal distribution and a close genetic relation to the above mentioned intrusive sheets, intercalated in the 'Rothliegende.'[2]

(δ) Silver-Lead Veins.

The veins of this type are characterized by silver-bearing galena and sphalerite, with high-grade silver ores in subordinate amount. Accordingly as the gangue is predominantly quartz, or carbonates, or barite, S. A. W. von Herder,[3] in treating the veins of the Freiberg district alone, established three subdivisions, which he called formations and which are in the main quite sharply defined, and are as follows:

9. The pyritic lead quartz formation.

10. The rich (high-grade) lead formation, also called brown spar formation or Brander formation, with carbonates.

11. The barytic lead formation, also called heavy spar formation or Halsbrück formation, with barite as the principal matrix.

These Freiberg vein-types have been found to exist with but little variation in the mineral districts of all parts of the globe, so that they are really of universal application. In using the terms originally chosen for the veins of Saxony, it is found that the term high-grade lead formation or brown spar formation proves to be too restricted, and it is changed to "carbon spar lead formation" (*i. e.*, carbonate gangue). The following detailed descriptions fully indicate the character of the various divisions.

9. The Pyritic Lead Deposits.

In the pyritic lead veins, quartz, galena, sphalerite, pyrite, arsenopyrite and chalcopyrite are most abundant. As accessory constituents of the

[1] A. Weisbach: 'Arsen Kupfer von Zwickan.' *Neues Jahrbuch f. Min.*, 1873, p. 64. H. Mietzsch: 'Erlaut z. S. Zwickau,' 1877, p. 36.

[2] A. v. Gutbier: Brief comment in *Neues Jahrbuch f. Min.*, 1843, pp. 460–461.

[3] S. A. W. von Herder: 'Der tiefe Meissner Erbstolln,' 1838, p. 17.

gangue, we have hornstone, jasper, ferruginous quartz, calcspar, siderite, more rarely brown spar and chlorite. As rarities, and occurring, as a rule, only in the vicinity of intersecting veins of a different nature, fluorspar, barite, nacrite, tetrahedrite and its argentiferous variety, silver glance, native silver, black silver ore, arsenical sulphide of silver and other high-grade silver ores are found. Witherite and smithsonite, too, are among the very rare occurrences in this formation.

The most important of these minerals to the miner is galena. In the Freiberg area it contains 0.1 to 0.2% of silver; elsewhere the percentage of silver is somewhat higher, but rarely more than 0.5%. Pyrite and arsenopyrite as a rule are very poor in silver, containing for the most part only 0.005 to 0.02% of it, rarely as high as .05%. The Freiberg sphalerite, always blackish, contains up to 0.03% silver and usually some tin, as noted by A. W. Stelzner and A. Schertel[1], owing to mechanically intergrown tinstone microliths.

The vein filling has a prevailingly massive structure, in which the ore minerals occur either commingled or in separate compact masses. More rarely the ingredients are arranged in bands.

One of the most important occurrences of this formation is found at Freiberg.

This mining field is a part of a gently undulating plateau, dissected by the moderately deep valleys of the Mulde and its tributaries. This plateau forms the gentle basal slope of the Erzgebirge, which rises to the northwest, while to the southeast a rather steep scarp forms the descent into northern Bohemia. The region of Freiberg, 400 to 450 m. (1,312 to 1,476 ft.) above tide, lies on the northwest side of the range, which trends southwest-northeast. This part of the range has a relatively much greater altitude than that lying to the southeast of the chain, which along the scarp just mentioned has been downthrown along a fault zone, commonly called the Bohemian thermal fissure. Biotite gneisses, with some subordinate intercalations of mica schist, form the country rock of the veins. These rocks at Freiberg are only approximately parallel in strike to the trend of the mountains, as they form a great dome or anticlinal uplift, the center of which coincides approximately with that of the city. The summit of this dome of Freiberg gneiss is cut by the ore-bearing fissures.

A great stock of granite breaks up through this dome, not in the center, but to the east of it, at Bobritsch-Naundorf. The eruptive dikes occurring in the field consist of mica diorite, a fine-grained mica syenite and quartz porphyry. These rocks, especially the last named, are all cut by the min-

[1] A. W. Stelzner and A. Schertel: 'Ueber den Zinngehalt und über die chemische Zusammensetzung der Schwarzen Zinkblende von Freiberg,' Freiberg, 1886.

eral veins. The porphyry dike of Muldener Hütton plays an especially prominent rôle in the mines. It may be traced with slight interruptions to a distance of about 20 km. (12 miles) from Frauenstein as far as the Nonnenwald, with strike north-northwest and thickness not exceeding 10 m. (33 ft.). The quartz porphyries cut through the high-grade silver quartz veins, but are themselves cut by the pyritic, barytic and rarely also by the high-grade lead lodes. The unfavorable influence of the quartz porphyry on the development of the vein fissures of the pyritic lead veins has already been referred to.

The mineral veins of the Freiberg district belong for the most part to this class of pyritic lead deposits; to a lesser extent to the high-grade silver and to the barytic lead types. In the northern, western and southeastern part of the district high-grade silver quartz veins are also found. As shown by their relation to the above mentioned eruptive dikes, these types of lodes are not of the same age. The high-grade silver quartz veins are the oldest; the barytic lead formation is the youngest. They also show some difference in strike. In general the Freiberg veins strike in two principal directions: (1) North-south to northeast, mostly north-northeast; these are the lodes of the pyritic and of part of the high-grade lead formation, as well as most of the representatives of the high-grade silver quartz formation; (2) northwest to west-northwest; to this group belong the barytic and another part of the high-grade lead ore lodes, as well as many barren lodes. The lodes of the first group are for the most part called 'stehende' (strike south-southwest to north-northeast), in part also 'flache' (strike north-northwest to south-southeast) and 'morgengänge' (strike west-southwest to east-northeast); those of the second group are called 'Spatgänge' (west-northwest to east-southeast), in part also 'flache' (north-northwest to south-southeast. (See page 121.)

The lead veins belonging to the category just mentioned are at the present time worked in the Himmelfahrt mine, owned by the State and situated close to the city, also in the Himmelfürst mine, also owned by the State, situated at Erbisdorf, near Brand, and, until recently, other veins were also worked in the Mord mine division of the Vereinigt Feld mine, near Brand, and in Junge Hohe Birke, between Freiberg and Brand, and still earlier in a very large number of other smaller mines. The veins for the most part have a thickness of only 0.1 to 0.8 m. (0.3 to 2.6 ft.), rarely over 2 m. (6.5 ft.). On the map of the Freiberg veins, accompanying the present work, the names of the most important representatives of this formation are given. Some of them have been found workable to considerable horizontal and vertical distances; for example, Kirschbaum or Hohe Birke Stehende to a distance of about 7 km. (4.2 miles) and a depth of 650 m.

(2,134 ft.) and the Selig Trost Stehende to a distance of 2.2 km. (1.3 miles) and a depth of more than 500 m. (1,640 ft.).

The pyritic lead veins were probably the first to be discovered in the Freiberg field, their gossan being very rich in secondary silver ores and especially in native silver. This discovery must have taken place about 1162 to 1170[1] and was followed by an immigration of miners from Goslar and other points of lower Saxony, who built the "Sächsstadt," the oldest part of Freiberg, which under that name was founded by Margrave Otto den Reichen, of Meissen, being subsequently fortified and further developed. In 1218 Freiberg is named for the first time in a document. The first mines mentioned in the documents, the Gottesgabe, Schöne Maria and Heiliger Gregorius, were probably located on the "Hauptstollngang" (main adit lode). After many vicissitudes, the silver mining industry of Freiberg attained a great period of prosperity between 1795 and 1870, during which time the production reached 45,000,000 to 60,000,000 oz. of silver a year. Somewhat earlier, on Easter, 1766, the Royal Mining Academy of Freiberg had been opened, and in 1776 the Royal Mining School. Despite great improvement in methods, the mining industry of Freiberg has, by reason of the depreciation of silver, ceased to be remunerative, and although the ore production and the output of silver and lead are still very considerable, and the works employ a large number of people, the Government has decided to gradually close down the mines. In 1901 the ore production in the Freiberg mining district was as follows: 11,563 tons silver ores, 6,195 tons arsenious, iron and copper pyrite, 28 tons of zinc-blende, 409 tons of barite. The output of silver was 17,573 kg., that of lead 2,090 tons. For every square meter of lode surface worked, there were produced 0.3 kg. silver and 37.73 kg. lead.

From the beginning of mining up to the year 1896, according to H. Müller, the total production was 5,242,957 kg. silver, worth about $227,000,000.[2]

Pyritic lead veins also occur elsewhere in Saxony, especially at Schneeberg and Annaberg. At Schneeberg, particularly at Kuttengrund

[1] H. Ermisch: 'Das Sächsische Bergrecht,' Leipzig, 1887, p. xvi.

[2] The following is a list of some of the more important publications upon the Freiberg veins: J. F. W. von Charpentier: 'Mineralog. Geographie der chursächsischen Lande,' 1778. H. Müller: 'Die Erzlagerstätten nördlich und nordwestlich von Freiberg,' Cotta's 'Gangstudien,' 1847, Vol. I, pp. 101-305. W. Vogelsang: 'Die Erzlagerstätten südlich und südöstlich bei Freiberg.' Cotta's 'Gangstudien,' 1848, Vol. II, pp. 19-133. H. Müller and B. R. Förster: 'Gangstudien aus dem Freiberger Revier.' With two plates. Freiberg, 1869. H. Müller: 'Die Freiberger Erzlagerstätten in Freiberg's 'Berg und Hüttenwesen,' 1883, pp. 28-84. 'Gangkarte der Freiberger Bergrevier.' H. Müller: 'Ueber die Erzgänge des Freiberger Bergrevieres.' A monograph accompanying the special geologic map of Saxony, 1901. (A comprehensive work, in course of publication.)

near Lössnitz, a peculiar variety of this type of deposit occurs, in which galena is subordinate to arsenical pyrite. The lodes produced 118 tons of arsenopyrite in 1898. At Annaberg this class exists in an aberrant form, since the deposits contain a predominance of copper ores, and cassiterite appears. Similar transitions to the copper formations were mentioned previously.

In this place one should also mention the many parallel veins which, according to E. Haber[1], traverse the Devonian shales of Ramsbeck, in the mining district of Brilon in Westphalia, the veins in the clay slate southeast of Trier in the Bischofsheim mine and those of the Aggerthal north of Siegburg, in the Rhenish Schiefergebirge.

Other veins which are not quite typical, since they differ from the examples just noted by the constant presence of siderite in the vein filling, are found in the mining district of Diez and Wiesbaden, on the lower Lahn, in Nassau.[2] Transitions to the class of carbonate-bearing lead deposits are also found there. Wenckenbach[3] divided the lead lodes of Nassau into seven reefs, of which the veins at Ems and Holzappel are the most important.

The vein system of Ems comprises all the veins occurring between Dernbach and Braubach. The most important are the Mercur vein at Ems and the Friedrichssegen at Oberlahnstein. It would be more accurate to designate these veins as a vein-group, since, in spite of their close association, they differ in strike and dip. They all occur cutting Lower Devonian clay slate, impure sandstone and quartzite belonging to the Upper Coblenz formation, whose beds strike northwest. The strike of the lodes lies between north-northwest and east-west. The predominant gangue mineral is a firm massive quartz, often cementing fragments of slate, while calcspar and brown spar occur sparingly. In the upper part of the veins siderite has altered to brown hematite, but in depth siderite is always present. The ores consist of argentiferous galena, with sphalerite, together with copper and iron pyrite. In the oxidized zone of the vein, white, green and brown lead ores occur frequently, together with occasional plumbo-resinite, native silver and copper, cuprite, chalcocite, azurite, malachite, lead sulphate and cuprous anglesite; at greater depths, gray copper, cobalt pyrite, nickel-arsenic-glance and bournonite, with other antimonial lead ores, are present. The structure of the veins is partly massive, partly banded. The thick-

[1] E. Haber: 'Der Blei-und Zinkbergbau bei Ramsbeck,' *Z.* f. d. B. H. S. u. S. im preuss. St., 1894, Vol. XLII, p. 77.

[2] Oberbergamtliche Beschreibung 'der Bergreviere Wiesbaden und Diez,' Bonn, 1893, pp. 91-116.

[3] Wenckenbach: 'Beschr. der im Herzogthum Nassau, etc., aufsetzenden Erzgänge.' Wiesbaden, 1861.

ness may be as much as 10 m. (33 ft.), and, in an exceptional case in the Friedrichssegen mine, as high as 20 m. (65 ft.)

As early as 1158, Emperor Frederick I. (Barbarossa) conferred on Archbishop Hillin of Treves the right to mine silver near Ems. Subsequently the Ems mining industry is said to have been flourishing in the 14th and 15th centuries. New enterprises began in 1743. Since 1791 the mines of Ems have been uninterruptedly in the possession of a company now called Emser Blei- und Silberwerk zu Ems, and have been continuously worked to the present time. The largest production of lead ores in the mining district of Diez, to which the Ems lodes belong, was reached in 1878-1880, with 22,539 to 24,611 tons per year.

The great Holzappel lode may be traced, according to Bauer,[1] from Holzappel on the Lahn, across the Obernhof, to the west of Singhofen, across Dahlheim, Ehrenthal, Werlau and Norath as far as Peterswalde, a distance of 50 km. (30 miles). In recent years the ore shoots in this lode at the Gute Hoffnung mine, near Werlau, described by L. Souheur,[2] have attracted much attention. Here the clay slates, sandy slates and sericite schists belonging to the lower Coblenz stage of the lower Devonian are traversed by a main lode with a parallel hanging-wall vein 10 m. (33 ft.) from it, both veins striking east-northeast, with a dip of from 50 to 90° southeast. The thickness is from 0.3 to 4 m., averaging 1 m. The fissure filling consists of quartz, sphalerite, galena and chalcopyrite, with fragments of country rock, and subordinate amounts of siderite and pyrite. The lode cuts the strata at an acute angle. The adjoining schists, as well as a parallel diabase dike in the overlying strata, are partly sericitized and are then called 'white rock' (weisses Gebirge). The lode is dislocated on its dip by flat dipping overthrust faults (so-called Deckelklüfte). Mention may also be made here of a similar vein at the Altglück mine, near Uckerath, not far from Sieg.

The structural relations of similar pyritic lead veins to eruptive dikes traversing Silurian shale is especially noteworthy in the Katzbach region of lower Silesia, and at Eisenberg, near Altenberg. According to Rosenberg-Lipinsky,[3] the veins accompany steep dipping dikes of olivine kersantite (olivine-mica-diorite) in such way that the kersantite either forms the middle of the lodes or is confined to one side. Dike-like intrusions of quartz porphyry also occur, and run at times parallel and close

[1] Bauer: 'Die Silber, Blei und Kupfererzgänge von Holzappel an der Lahn, Wellmich und Werlau am Rhein.' *Karsten's Archiv* f. Bergb., etc., Vol. XV, 1841.

[2] L. Souheur: 'Die Lagerstätte der Zink, Blei und Kupfererzgrube Gute Hoffnung bei Werlau am Rhein,' *Jahrb.* d. k. preuss. geol. Landesanst, 1892, p. 96.

[3] V. Rosenberg-Lipinsky: 'Beiträge zur Kenntniss des Altenberger Erzbergbaues,' *Jahrb.* d. k. preuss. geol. Landesanst, 1894, pp. 161-182. With list of previous works on the district.

to the ore-bearing fissures. The fissure filling of the mineralized veins consists of clay, fragments of shale and olivine kersantite, arsenious-copper pyrite (arsen-kupfer-schwefelkies), galena, tetrahedrite and rarely of zinc-blende, antimonite, boulangerite, epiboulangerite and bournonite, as well as quartz. Of the ores just named, arsenopyrite is by far the most abundant, constituting about 40 to 50% of the ore. The copper pyrite is gold-bearing. This gold content and the richness in arsenopyrite, as well as the presence of gray copper, establishes a close relationship between these lodes and those of Hohenstein in Saxony, whose more highly copper-bearing variety was described previously. The Altenberg mining industry, which is said to have been flourishing in the thirteenth century, was forgotten for a long time and again resumed lately.

As a typical example in Austria, the old and famous lodes of Kuttenberg[1] in Bohemia may be noted. The region consists of gneisses, in part overlain by Cretaceous strata. The gneiss is traversed by a great number of veins which may be grouped into 18 series, with uniform north-south strike and steep dip east or west. The filling is of quartz, hornstone, fragments of the country rock, calcite, ankerite, pyrite, zinc-blende, argentiferous galena and arsenopyrite, with rare native silver, zincite, boulangerite, proustite, siderite, cronstedtite and lillite. The district is 6.5 km. (3.9 m.) long and 4.5 km. (2.7 m.) broad. The mining industry dates back to the beginning of the thirteenth century, flourished in the fourteenth century, and its revival was recently attempted.

The lodes in the pre-Cambrian clay slate at Mies,[2] Bohemia, which are distinguished by uncommonly large druse cavities, form a transition to the barytic lead deposits by reason of the presence of a little barite.

Among Hungarian deposits, the Schemnitz lodes belong to or are closely related to the pyritic lead veins. As they are, however, rich in gold and silver, they will be included in that class of veins instead of the one treated here.

In Spain veins of pyritic lead ores are of considerable importance, especially at Linares in the province of Jaen, in the eastern part of the Sierra Morena; at L'Horcajo in the province of Ciudad Real, and at Castuera in the District of Badajoz.

The mining field of Linares is, according to Caron,[3] about 12 km. (7.2 m.) long and 9 km. (5.4 m.) broad, lying north of the town on an arid plateau and rocky hilly country south of the Sierra Morena proper. The

[1] F. Katzer: 'Der Kuttenberger Erzdistrict,' *Oesterr. Z. f. B. u. H.*, 1896, p. 247 *et seq.*

[2] F. Posepny: 'Der Bergbaudistrict von Mies,' Vienna, 1874.

[3] Caron: 'Bericht über eine Instruktionsreise nach Spanien im Jahre 1878.' *Z.* f. d. B. H. u. S. im preuss. St., 1880, Vol. XXVIII, p. 119.

whole region consists of granite, which on the south and west is overlain by clays, sandstones and conglomerates of uncertain age while at the north it adjoins the Silurian shales, forming the high mountains. The veins are in the granite, only few of them continuing into the shales. Their strike is in the main northeast and their dip is quite steep. In general they are relatively thick, reaching eight meters in La Cruz lode. The veins are often quite long, exceeding 1 km., while the Alamillos lode is 6 km. (3.6 m.), and La Cruz and Arrayanes veins 4 km. (2.4 m.) long. The veins are exceedingly rich, as gangue and country rock form but a small amount of the fissure filling. The total thickness of a lode is often filled with the galena, not very rich in silver it is true, but mingled with very little blende and a small amount of pyrite. The gangue is mostly quartz, with small amounts of calcspar, dolomite, barite and siderite. Copper ores occurred in the outcrop. The average silver content of the ores is stated to be 180 gm. (5.3 oz.) silver per ton. The Arrayanes mine, belonging to the State, and La Fortuna, belonging to an English Company, are the principal mines. The ancient Phoenicians, Carthaginians and Romans had mines in this region. The old shafts situated north of Linares, on the Cerro de Val de Infierno, are called to this day "Pozos de Anibal" (Hannibal's wells). The most brilliant period of recent mining in that district was about 1889, when the production of lead in the province of Jaen rose to 188,325 tons.

Deposits of this class also occur in France. A great vein which occurs in the Silurian shale of Pontpéan, in the vicinity of Rennes, and the lodes of Huelgoat and Poullaouen (Finistère) in granite and in the adjoining Paleozoic shales are the most noteworthy. The two last named localities were formerly the most important lead mines of France, but they are now abandoned.[1]

The main vein of La Touche mine, in the neighborhood of Rennes,[2] is of considerable geologic interest and deserves a brief description. The lode occurs in granite and has been traced for about two km. (1.2 m.); some of its orebodies have been opened up to a depth of more than 100 m. Its strike is north-south, its dip 70° east. It is a very characteristic double vein. In all parts of its known extent a gray breccia-like quartz, barren of ore and 5-10 meters thick, forms the lower and larger streak of the vein. In the hanging-wall of this, but only about certain ore-shoots, the true ore-bearing branch vein is developed. The ore consists of argentiferous galena, argentiferous zinc-blende and pyrite with quartz, chalcedony and horn-

[1] Fuchs and De Launay: 'Gîtes Mineraux,' II, p. 498-509.

[2] According to a brief communication of W. Frhr. von Fircks, and specimens in the Freiberg museum.

stone as gangue minerals. The structure is either banded or brecciated. A peculiarly mottled ore, occurring in the vein, consists of sharp angled splinters of the quartzose lower stringer, which are coated with several layers of chalcedony and cemented by zinc-blende and hornstone. Parts of the country rock are not infrequently found enclosed. The granite in the hanging-wall is decomposed to a distance of 1.5 meters and impregnated with finely divided ore; in the immediate vicinity of the lode itself, the granite has frequently been altered into a clay. Away from the ore-shoots, the upper streak of the vein narrows from a thickness of 1-2 meters down to a thin hornstone layer.

Examples of this class, very rich in silver, occur, according to Vogt, in Svenningdalen district of northern Norway.[1]

In the United States examples of this class occur at Bingham,[2] Utah, the veins consisting of quartz and galena, together with pyrite, chalcopyrite and blende, with a gossan which was rich in silver. This class also includes the veins of the Clear Creek district in Colorado.

10. Veins of Spathic Lead Ore.

In this class the gangue consists essentially of the carbonates, calcspar, brownspar, rhodochrosite, siderite and quartz. The ore minerals are argentiferous galena, argentiferous sphalerite, and, less often, pyrite, marcasite, tetrahedrite, both with and without silver, together with high-grade silver ores, especially ruby silver and argentite. The structure is usually imperfect and but seldom well banded. The ore minerals frequently occur sprinkled through the gangue.

In the Freiberg district proper, this class of veins is especially developed in the Himmelsfürst and Bescheert Glück mines near Brand (see page 245), where they exist as high-grade lead ores or the brownspar formation. The high-grade 'noble' veins of that locality are, according to H. Müller,[3] distinguished by their composition, consisting of brownspar and rhodochrosite, galena, sphalerite, argentiferous and ordinary tetrahedrite, antimony-silver blende, silver glance and native silver. The subordinate minerals are quartz, hornstone, calcspar, siderite, pyrite, arsenopyrite and copper pyrite, stephanite and polybasite; nickeliferous pyrrhotite, native arsenic, pitchblende (Uranpecherz), etc., are rarely observed.

[1] J. H. L. Vogt: 'Söndre Helgeland,' Norges Geol. Undersög., No. 29, Christiania, 1900, and *Zeit. f. Prak. Geol.*, 1902, pp. 1–8.

[2] J. M. Boutwell: 'Ore Deposits of Bingham, Utah,' *Bull.* 213, U. S. Geol. Survey, 1902, pp. 105-122, also 'Economic Geology of the Bingham District, Utah,' by Boutwell, Keith and Emmons, Professional paper No. 38, U. S. Geol. Survey, 1905.

[3] 'Litteraturangaben,' p. 249.

The galena contains between 0.4 and 0.6%, and in some cases as high as 2% silver. A very characteristic feature is the so-called glazed blende, a dark zinc-blende with microscopic inclusions of silver glance (Glaserz) and possibly other high-grade silver ores, having a silver content of as

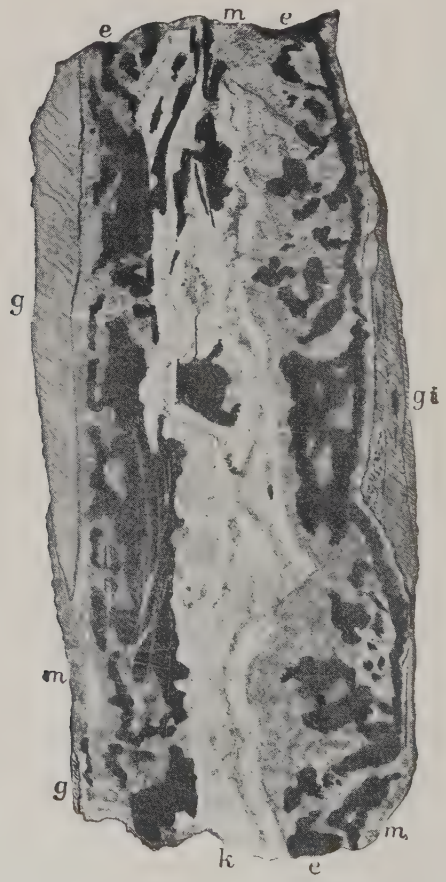


Fig. 154.—Section across Verbogen Flachen in the Himmelsfürst mine (carbon spar lead formation). (From nature.)

g, gray decomposed gneiss; gi, gneiss impregnated with pyrite and copper pyrite; k, calcspar and brownspar; m, rhodochrosite; e, argentiferous blende and some gray copper.

high as 1.5%. Even the pyrite in this formation often contains as high as 0.2% silver. When a banded structure is developed in these lodes, zinc-blende and galena, together with rhodochrosite and brownspar, are usually found concentrated immediately along the selvages, while in the middle

calcspar, and at times quartz predominates. Fig. 154 shows the manner of development of these veins, whose thickness usually amounts to 0.08-0.75 meters, rarely over 1.5 meters.

The reproduction of a thin section, Fig. 155, gives an idea of the manner of microscopic intergrowth between the gangue and ore minerals.

Most of the lodes of this kind, including the most important examples in the Freiberg district, have a low strike (11.4 to 12.4 hours) (see page 130), with flat dip of 40 to 60° west. According to H. Müller, another important parallel reef follows the main direction north-northeast to northeast and

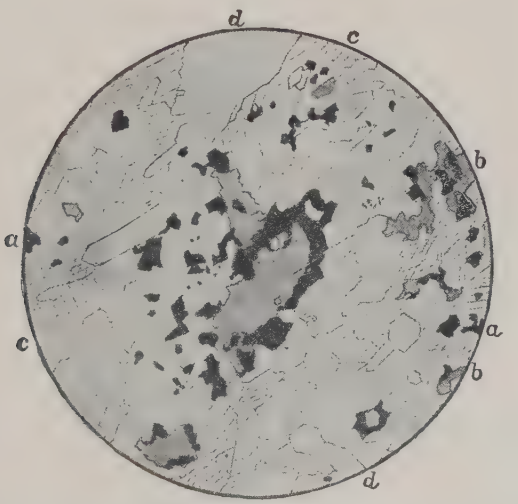


Fig. 155.—Thin section of ore of the Silberfund St. auf Himmelsfürst. (Magnified 50 diameters.)

Shows the inner core of zinc-blende (b), with argentite and gray copper (a), and calcite and brownspar (c), as well as quartz (d).

dips steeply 70° to 90° southeast or northwest, as illustrated by the Dorothea and the Silberfund veins of the Himmelsfürst mine, the Neuglückstern, and the Johannes and David veins of Bescheert Glück. A peculiar development is shown by the Habacht stringers in the Bescheert Glück and Einigkeit mines. They strike northeast and dip northwest at no more than 15° to 40°. They are narrow veins, consisting mainly of rhodochrosite and quartz, argentiferous gray copper and argentiferous galena. In the aggregate 350 of these high-grade lead lodes are known. They have been opened up over a distance of 600-1,000 m. (1,968-3,280 ft.), while a few like the Neue Hohe Birke Stehende are worked for a distance

of 2 km. (1.2 miles.) A somewhat abnormal character is shown by the vein of the Güte Gottes mine at Scharfenberg near Meissen, discovered in 1225 and worked anew from 1867 to 1898. According to H. Zinkeisen, the vein

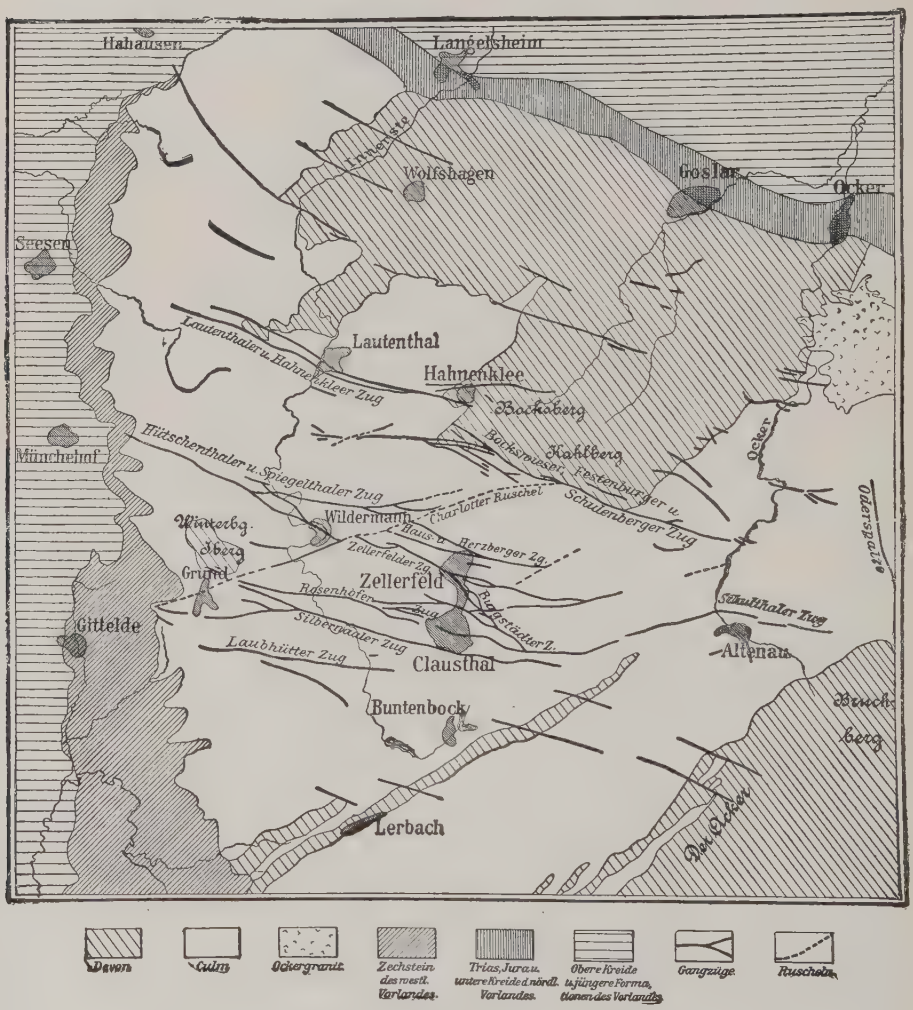


Fig. 156.—General sketch of the lode system of the Upper Harz.
1, Devonian; 2, culm; 3, ochre granite; 4, zechstein foot-hills; 5, Jura-Trias and Lower Cretaceous; 6, Upper Cretaceous and younger formations of the foot-hills; 7, veins; 8, Ruscheln.

fissures occur in the granite-syenite massive of Meissen. They contain quartz, brownspar, rhodochrosite, celestite and galena, with an average silver content of about 0.20 to 0.30%, and a yellow blende almost as rich

in silver, together with gray copper having as high as 8% silver.[1] The veins also include great masses of vein clay and granitic friction débris. The accessory constituents include strontianite, barite, gypsum, pyrite, copper pyrite, very rarely also glass ore (earthy argentite), ruby silver and native silver.

The stringers and veins form a zone of 2 km. (1.2 m.) long, and 600 m. (1,968 ft.) wide, and striking northeast. The thickness of the veins, about 50 of which are known, varies from a few centimeters in the small stringers to 2 meters in the Heinrich Morgengang. All the veins show a propensity to fray out in stringers, and to take an irregular course. They are often dislocated by transverse faults, and by the so-called "Schwebenden," which are horizontal, or nearly horizontal, narrow clay fissures or movement planes, only rarely carrying ore. The filling of the veins and stringers is usually massive. Quartz and brownspar, intimately mingled, contain the ores in scattered particles. More rarely the metallic minerals are found in compact, coarsely crystalline bodies of nearly pure ore, which in such cases are crossed in all directions by veins of hornstone. A banded structure occasionally appears, ordinarily with streaks of blende along the two selvages and with a central often breccia-like part, consisting essentially of brownspar and rhodochrosite.

The Clausthal Veins.

In the Harz, the famous lodes of the Clausthal area are, for the most part, closely related to the carbonspar-lead formation. According to F. Klockmann,[2] the Clausthal district (see general map Fig. 156) comprises an area 18 km. (10.8 mi.) long and 8 km. (4.8 mi.) broad, part of the North German plateau in the region of Clausthal, Grund, Wildemann, Bockswiese and Schulenberg. This plateau, whose elevation is 550-600 m. (1,804-1,968 ft.) above sea level, rising in the Schalke to a height of 764 m. (2,506 ft.) forms a part of the northwestern upper Harz range, which drops down northward and westward with steep scarps to the foot-hills. To the southeast the plateau is bounded by the Bruchberg range, to the north by the mountain wall of the Bocksberg and the Kahleberg. The entire area is formed of the nucleal rocks of the Harz; that is, of Devonian and Lower Carboniferous beds, especially the Culm, whose lower division consists of clay shales and silicious shales, while the upper division is mainly gray-

[1] H. Zinkeisen: 'Ueber die Erzgänge von Güte Gottes zu Scharfenberg.' Freiberger *Jahrb.*, 1890, pp. 40-64. Gives also the older literature of H. Müller.

[2] F. Klockmann: 'Die Erzlagerstätten des Oberharzes im Werke Berg und Hüttenwesen des Oberharzes,' 1895, pp. 43-65.

wacke. Lying unconformably upon the upraised edges of these Paleozoic rocks, close to the west edge of the mountains, are the strata of the Zechstein formation. The Devonian and Culm strata have been squeezed together into northeast folds with associated overturns and overthrusts, with many true fault fissures. Overthrust zones also occur as the so-called *Ruscheln*, lode-like formations, filled with strongly folded or crushed and mashed country rock, called Gangthonschiefer (vein clay slate). In the vicinity of Clausthal, the well-known Faule Ruschel, with nearly east-west strike, crosses the main Burgstadt series and the so-called Charlotte lode. Many veins are true fault fissures, as shown by A. von Groddeck,[1] and, still earlier, by Schmidt. Other fault lodes at Bockswiese displace the Devonian by about 200 m. (656 ft.), as determined by the dislocation of the Culm beds (Fig. 94).

The vein system of Clausthal consists of several series of veins, often convergent and which frequently fray out. The following may be distinguished from north southward:

1. The Gegenthal-Wittenberg series.
2. The Lautenthal-Hahnenkleer series.
3. The Bockswieser-Festenburg-Schulenberg series.
4. The Hütschenthal-Spiegelthal series.
5. The Haus Herzberg series.
6. The Zellerfeld main series.
7. The Burgstädt series.
8. The Rosenhöfer series.
9. The Silbernaaler series.
10. The Laubhütte series.

The length of each series along the strike is considerable. The Schulenberg series has been traced for a distance of 10 km. (6 m.); the Gegenthal-Wittenberg series is probably much larger. Without exception, they all have a strike of from southwest to west, and dip, almost without exception, south at 70 to 80°.

They consist wholly of compound lodes, mostly with a distinct footwall selvage, but passing into the hanging-wall country rock by a gradually diminishing succession of stringers. They are, therefore, not solid fissure fillings, but zones of stringers or zones of sheeting which may be as much as 40 m. (131 ft.) across. A good idea of this stringer formation is afforded by Fig. 157, after Zirkler.[2]

[1] A. v. Groddeck: 'Ueber die Erzgänge des Oberharzes.' *Zeitschr. d. Deutsch geol. Ges.*, 1866, pp. 693-776. Also, 'Geognostischen Durchschnitten durch den Oberharz' *Z.* f. d. B. H. u. S. im preuss. St., 1873, pp. 1-14.

[2] Zirkler: 'Essener Glückauf,' 1897, Vol. XXXIII, p. 73.

The Rosenhofer series of veins scatters in passing into the Ruscheln, while in the Zellerfeld and Burgstädter series some veins are deflected, while others pass through with unaltered course.

As has been noted, all the veins are probably fault fissures, though this is hard to prove in the case of the lodes occurring in the monotonously similar beds of the Culm.

The vein filling consists of ore, gangue minerals and fragments of coun-

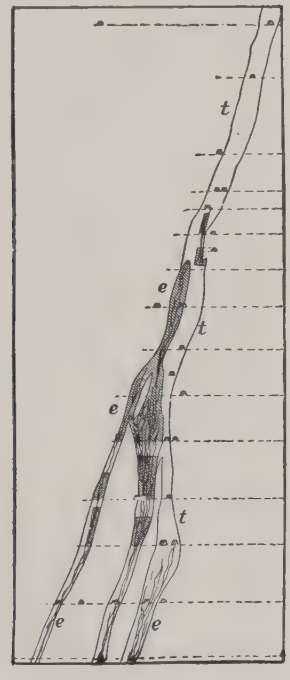


Fig. 157.—Cross-section through the main veins of the Bergmannstrost mine, 70 m. east of the Marien shaft. (Zirkler.)
e, ore-carrying; t, barren veins. The dark places have been worked out

try rock. The predominant ore is argentiferous (0.0—0.3%) galena, with associated zinc-blende, which predominates at Lautenthal, with subordinate copper pyrite, pyrite and marcasite, and rarely tetrahedrite and bournonite. Among the matrices, quartz and calcspar are predominant, except in the Silbernaaler and Rosenhöfer vein series, which are rich in barite; siderite, pearl spar and strontianite also occur. The rock fragments consist of hard sandy slate in angular fragments or of crushed clay slate. The inclusions often far exceed the ore in bulk. In many cases we find an irregularly

massive lode structure, and not infrequently 'ring ore' is developed, especially in the lodes of the Ring and Silberschnur mine at Zellerfeld (see Fig. 135-137).

According to A. Lengemann, the silver-lead mining industry began in the Clausthal district about 1220, was abandoned in 1350, but resumed in 1526. In this second period it was at first concentrated around the newly founded mining town of Zellerfeld. Clausthal did not obtain a mining grant until 1554. The greater part of the mining population of the upper Harz came from the upper Erzgebirge in the 16th century. In 1811 the mining academy of Clausthal was founded, a one-year course for prospective miners having been introduced in the Clausthal lyceum as early as 1775.

The mines on the Clausthal plateau (Clausthal, Lautenthal and Grund) produced, in 1898, 196,985 tons of crude ore.

The lodes of Neudorf-Harzgerode, in the eastern Harz of Anhalt, depart even further than those of Clausthal from the typical high-grade (noble) lead deposits.[1] At Neudorf-Harzgerode the plateau of upper Silurian slate is traversed by several vein systems very nearly parallel to one another, among which the Dillenberg lode, with the mines of Pfaffenberg and Meisenberg, is the most important. This double vein consists of a true lead vein and another of spathic iron ore. The two are either directly in contact or are separated only by a narrow layer of rock. The ore vein, which is often split up into stringers, consists of siderite, quartz, calcspar, fluorspar, galena, zinc-blende, gray copper, pyrite, copper pyrite, bournonite, sometimes with the addition of hübnerite, scheelite and wolframite. The silver lead ores of the Neudorf mine contained, towards the end of the seventies, on an average 40% lead and 0.061% silver. The spathic iron ore appears now above, now below, and may attain a thickness up to 4 m. (13 ft.). An abundance of fluorspar and the occasional presence of other minerals, characteristic of tin deposits, distinguishes the Neudorf lodes from the normal type of 'rich' lead veins.

A good Austrian example of this type occurs at Pribram, in Central Bohemia.

The Pribram lode area proper lies in a mountainous region 500-550 m. (1,640-1,804 ft.) above sea level. The prevailing rock is a quartzitic grit (greywacke), which, though it has not yet yielded any fossils, is probably Cambrian. In some beds it becomes conglomeratic; in the vicinity of the Lill shaft intercalations of oolitic limestone occur, as indicated by blocks

[1] Heinr. Credner: 'Uebersicht der geogn. Verh. Thüringens und des Harzes,' 1843, p. 123. Kegel: 'Beitrag zur Kenntniss der Neudorf-Harzgeroder Gänge,' *Berg. u. Hutten Zeit.*, 1877, pp. 397-400. C. Blömeke: 'Ueber die Erzlagerstätten d. Harzes,' Vienna, 1885, p. 85. H. Fischer: 'Gutachten über die Anhaltinischen Blei- und Silberwerke,' 1894.

scattered thereabouts. The strata form a trough, as indicated in the section after J. Schmid, Fig. 158. To the southeast below this trough, clay

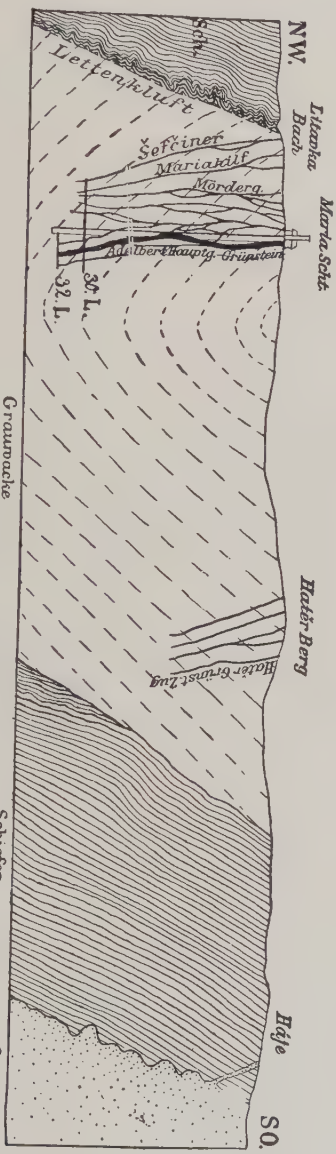


Fig. 158.—Section through Grünstein vein-series of Přibram. (J. Schmid.)

slates, probably of Cambrian age, are traversed by granite and altered by contact metamorphism. The hornfels immediately adjoining the contact

is crossed in all directions by fine-grained granite apophyses. The exact relation between the grits and the shales does not appear to have been quite made out. In the section an uncomformity between these two rocks

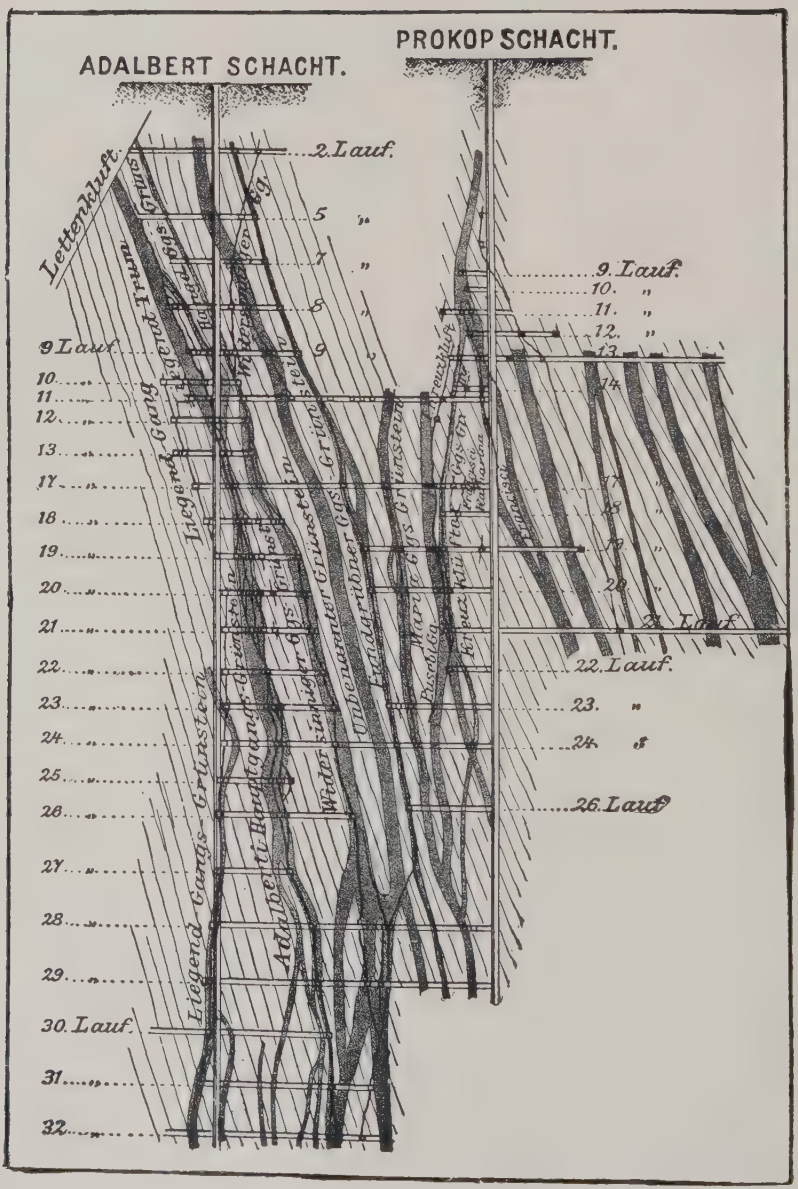


Fig. 159.—Section through Adalbert and Prokop shafts. (J. Schmid.)

is assumed. At the northwest edge of the greywacke trough the stratification has been interrupted by a fault, dipping steeply northwest, and filled with a clayey mass or with highly decomposed material, folded in a most complicated manner, the so-called Lettenkluft (clay fault), most probably an overthrust fault, along which the greywacke beds abut sharply against a second slate zone. The minute folding of the adjoining slate is indicated in the section. Quartzitic graywackes recur further northwest.

Where the ore veins occur, at Bohutin and Birkenberg, the trough of Cambrian grits is traversed by numerous greenstone dikes, often swelling into stock-like forms 1 to 30 m. (3 to 98 ft.) thick. The rocks are mostly diabases, rarely diorites. These dikes of igneous rocks are followed by the lodes, the mineral veins either clinging to the selvages or running through the middle of the dike and parallel to its contact. The section, Fig. 159, based on surveys by J. Schmid, as well as the ground plan in Fig. 160, by the same author, gives a clear representation of this close connection between the veins and the greenstone dikes. Besides the eruptive masses thus far named, a quartz diorite mass encountered in the mining operations west of the Stephan shaft at Bohutin is noteworthy because the mineral veins in passing from the sandy slate into this quartz diorite lose the lead and silver ores and carry antimony ores instead. This eruptive stock is surrounded by a contact zone.

The most important and richest of the Pribram lodes occur in a narrow belt, 4 km. (2.4 miles) long, running southwest and northeast along the Lettenkluft (clay fissure). Where the lodes, issuing from the grit, run into the clay fissure, and up against the greatly folded clay slate, they contract decidedly and become almost barren, or they split up into several insignificant stringers, which are often found to be deflected eastward. Some of them indeed have been followed beyond the 'clay fissure' into the slates, but there they turned out to be much poorer than in the grit, and as a rule carried only spathic iron ore, brownspar and calcspar, as well as some blende. In the granite area, mineral veins are also known, both iron- and lead-bearing ones, as, for example, at Milin and Vrancice, but they are not of economic importance.

Within the graywacke, the veins have, as a rule, the following character: Down to a remarkable depth, usually 60 m. (196 ft.) in the Segen Gottes shaft southwest of Pribram, in the Liegend lode, and in the Nordwest lode even to 270 m. (885 ft.), the ore is altered to a gossan, consisting of brown iron ore, cerussite, pyromorphite, malachite, native silver and secondary silica as chalcedony. At greater depths the veins assume the character of sulphide lead veins, mostly of the character of the spathic lead formation. The veins, according to J. Schmid, consist, in the richer por-

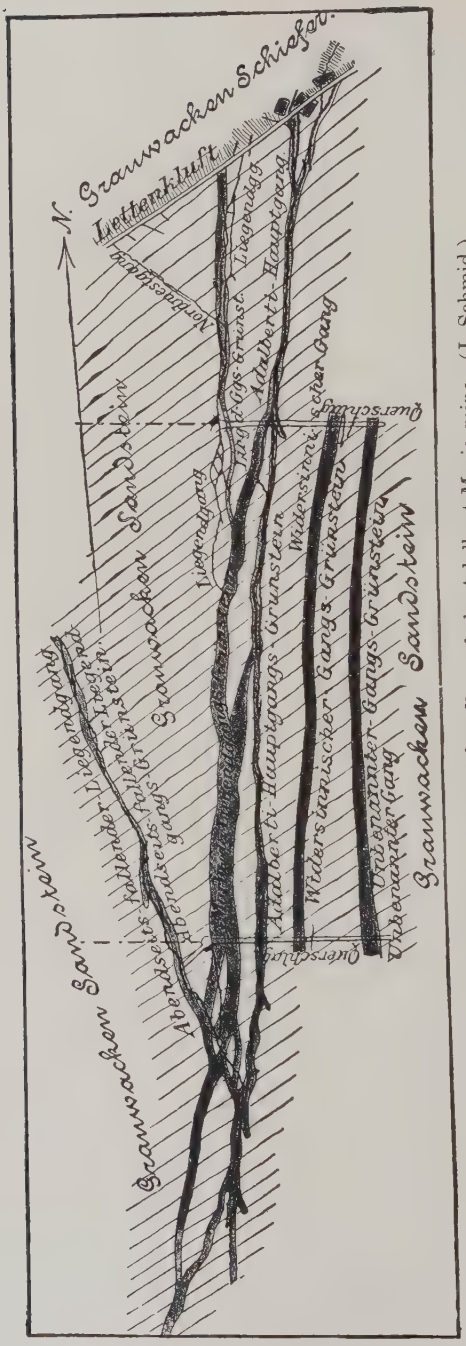


Fig. 160.—Ground plan of the 24th gallery of the Adalbert-Maria mine. (J. Schmid.)

tions, mainly of compact argentiferous galena, zinc-blende, siderite, quartz and calcspar, in the barren portions of only iron spar and calcspar

The silver content of the galena varies between 0.1 and 0.7%, and it was not possible to ascertain whether there was a decrease in the content with increase in depth. The zinc-blende is generally, though but feebly, argentiferous (0.04—0.06%). Higher percentages are rare. Besides the minerals just named, fragments of the country rock also occur frequently in the midst of the vein filling. The structure of the latter is sometimes massive, banded or with stringers of ore. The illustration of the lode in

Fig. 161.—The Adalbert main vein at Pribram. (J. Zadrazil, reproduced by J. Schmid.)
G, graywacke; D, diorite; q, quartz; c, calcspar; g, galena; b, zinc-blende.

Fig. 161, taken from the official report on Pribram, shows the Adalbert main lode, and illustrates a type which is of common occurrence there.

In the Anna mine and elsewhere, especially in the deep workings, another kind of lode filling often occurs, called there Dürrerz (dry ore); approaching the character of the high-grade quartz formation of the Freiberg area. A matrix rich in quartz, but poor in carbonates, carries, besides silver-bearing galena, ruby silver ore, native silver, stephanite, gray copper ore and stibnite, mostly in disseminated grains.

The filling of the fissure often consists of several bands quite sharply divided from one another, a galena band, one or two bands of dry ore and

a younger one of calcspar. The dry ores steadily increase in amount with increasing depth.

The thickness of the Pribram veins varies, according to J. Schmid, from nothing up to 8 m. (26 ft.). The most important veins are the main Adalbert vein, the Abendseitsfallende (westward dipping) Liegend vein, the northwest vein, the Adalbert Liegend vein, the Fundgruben vein, the Eusebi vein and the Widersinnige (contrary) vein.

The silver mining industry of Pribram is stated to date back to 843. In recent time the production has vastly increased. In 1898 it amounted to 263,979 tons of crude ore. From this were obtained 20,882 tons of pure ore, with 38,599 kilograms of silver and 4,826.1 tons lead. The ore delivered at the furnace contained on an average 0.185% silver and 23.10% lead. The work has been carried to extraordinary depths, in the Adalbert shaft to 1,099 m. (3,606 feet).[1]

Another undoubted example of this type of deposit occurs in the Austrian Alps, at Metnitz and Zweinitz, in Carinthia.[2]

The silver lead deposits of Mazarrón, in the Spanish province of Murcia, which were mined by the ancient Romans, have become notorious by their dangerous eruptions of carbon dioxide. The basal rocks consist of micaceous and talcose slates, passing into argillaceous, chloritic and amphibole schists, and of crystalline limestones. These are covered by Tertiary strata, which are cut by rhyolite stocks. The north-south mineral veins which cut these stocks at the Cabeza de San Cristobal are thus proved to be of very recent age. As the veins pass into the slate they quickly wedge out. One vein, Las Laguenas, clings close to the contact between the two rocks. The vein filling consists of disintegrated rhyolite, silver-bearing galena, blende, pyrite and siderite. At a depth of 400 to 500 meters the veins become impoverished. The horizontal length is also small, but the veins sometimes reach a thickness of 16 meters (52 feet).

The outbursts of carbon dioxide always take place when slate is struck, and are accompanied by large outflows of warm water at 35° C. (95° F.) The rapid diffusion of the gas and the hurling of rock fragments by these

[1] The most important publications include: W. Vogelsang: 'Die Pribramer Erzniederlage.' Cotta's Gangstudien, I, 1850, pp. 305-329. John Grimm: 'Die Erzniederlage von Pribram,' 1855; and several later essays by the same author. Babanek: 'Zur Kenntniss der Pribramer Erzgange.' *Oesterr. Z. f. B. u. H.*, 1878. J. Schmid: 'Bilder von den Erzlagerstätten zu Pribram.' Published by the Imperial Royal Ministry of Agriculture, 1887, with atlas. Contains a bibliography of the subject. F. Posepny: 'Beitrag zur Kenntniss der montangeolog. Verhaltnisse von Pribram.' *Archiv* f. Prak. Geol., II, Freiberg, 1895, pp. 609-745.

[2] R. Canaval: 'Die Blende und Bleiglanz führenden Gänge bei Metnitz und Zweinitz in Kärnthen.' Carinthia, II, No. 4, 1899. D. F. Villasante y Gomez: 'La industria de Mazarrón,' 1892. 'Sur les filons de Mazarrón,' *Revista Min.*, No. 1393-1396, 1902. D. F. Iznardi u. a. *Revista Min.*, 1902, No. 1873.

outbursts caused repeated accidents. An eruption of gas in the Triumfo mine at a depth of 440 m. (1,443 ft.) produced 200 cubic meters of débris and filled the levels with the gas.

As an American example of the carbonspar lead ore formation we will mention the Enterprise mine at Rico, in southwestern Colorado. According to T. A. Rickard,[1] the gently dipping Lower Carboniferous slates, limestones, and sandstones of this locality are traversed by two systems of veins. One set has a northeast course and very steep dip; the other strikes north-south, and has a low dip. The fissures of the former are ore-bearing; those of the latter are of importance only as 'cross veins' enriching the others, being themselves merely lean quartz veins, much too poor to pay for working. The ore-veins cannot be followed up beyond a definite horizon, the so-called 'contact.' This contact is between high fissured limestone, overlain by solid but warped shales. Within the 'contact zone' lateral infiltration from the tops of the veins has produced rich deposits of banded ore. Followed downward the mineral veins continue, but their character changes. At 30 to 45 m. (98 to 147 ft.) below the 'contact zone' the ore and rhodochrosite disappear and the veins below this depth contain only barren quartz and crushed country rock. All the veins are fault fissures, with but slight throw and a thickness rarely exceeding a foot. (0.3 m.) Their physical development depends greatly on the nature of the country rock. In the sandstone the veins are formed by a single fissure; in the limestone the fracture splits up into a number of stringers. The filling consists of rhodochrosite and quartz, with galena, zinc-blende, pyrite, copper pyrite, argentite and stephanite. They often show a remarkably well banded structure in which the quartz crusts show comb structure. At one point the veins change from their normal development, as silver veins with carbonate gangue, and occasionally carry native gold, besides native silver. Thus their example represents a transition of the carbonspathic lead ore formation to the silver-gold ore formation.

The ore of the Rico district was discovered as early as 1864, but it was only in 1881 that an active and remunerative mining industry began to develop, at the Enterprise, Rico and Aspen mines.

This class also includes the silver-lead veins occurring in the quartzites of the Coeur d'Alene Mountains in Idaho, whose main gangue is siderite (see later).

As an extreme member of the carbonspathic lead type of vein we have the two pure zinc-blende veins, with calcspar and some hornstone as gangue, which occur in the granite at Merklin, southwest of Pilsen in

[1] T. A. Rickard: 'The Enterprise Mine, Rico, Colorado,' *Trans.* of the Am. Inst. Min. Eng., XXVI, 1897, p. 906 *et seq.*

Bohemia. According to E. Rüger they strike northwest, and belong structurally to the lead vein system of Mies. The southwestern vein especially has been extensively mined, though work has recently been suspended. The lode matter contained many angular fragments of decomposed granite embedded in it, and also in places lenticular masses of impure graphite lying across the strike. When the vein was narrow the mineral filling consisted of nothing but zinc-blende; when of greater thickness the filling was calcspar, with blende, in which case the country rock also was found to be impregnated with blende. In the upper portions smithsonite and calamine were found. A very remarkable phenomenon is the fact that the zinc-blende veins on passing into the pre-Cambrain (?) clay slate contain more and more galena, until this mineral finally predominates. Merklin was founded in 1842. The annual production sometimes amounted to 2,000 tons of zinc-blende ores, with a zinc content of about 52%.

11. Barytic Lead Veins.

In this class of veins the gangue consists of predominant barite with fluorspar and quartz or jasper besides calcspar. These minerals are generally intergrown in a remarkably thin-banded structure. The barite especially occurs in finely crystalline crusts (calc-barite), the fluorspar in diverse tints, but mainly green and yellow. The ore minerals, which either form thin crusts or appear sprinkled through the gangue, consist of argentiferous galena, often developed in large flakes, pyrite and marcasite, also zinc-blende, copper pyrite, gray copper and at times rich silver ores.

In the Freiberg mining district (see page 238), the most prominent representatives of this formation are found in the region of Halsbrücke, where the Halsbrücke Spat and the Drei Prinzen Spat called for special mention. These lodes all strike northwest, and ordinarily dip steeply northeast. At Halsbrücke itself they traverse biotite gneiss; farther north they cut through mica schist and granulite. The main veins are distinguished by their thickness, usually 1 to 4 m. (3 to 13 ft.), at times up to 6 m. (19 ft.). They are the youngest of the Freiberg veins, often traversing and dislocating both the pyritic and the high-grade lead veins. On the Halsbrücke Spat, according to H. Müller "besides the normal, so-called soft band, carrying lead ore poor in silver, there is also a so-called hard band, consisting essentially of crystalline and jaspery quartz with thinly laminated barite, fluorspar, argentiferous tetrahedrite, galena, carrying 0.02-0.08% of silver, antimonial silver blende and arsenical silver blende, bournonite and copper pyrite. The two main bands of the lode diverge toward the northwest in the mining field of Kurprinz Friedrich August Erbstolln near Gross-

schirma, and are there worked as separate veins, the soft one under the name of Drei Prinzen Spat (see Fig. 130), the hard vein under the name of Ludwig Spat."

Aside from the main representatives just named, the barytic lead veins of the Freiberg area proper are not particularly rich. They show a peculiar behavior at points where they cross older veins, especially the pyritic lead veins. At these crossings they carry rich silver ores, 'edler Geschicke,' including especially argentite, ruby silver, acanthite, polybasite, stephanite, native silver and tetrahedrite, ordinarily in a carbonate gangue. In rare cases the veins also carry nickel and cobalt ores. Such rich intersections were especially productive in the Himmelfahrt mine directly outside the town, especially at the crossing of the Neu Hoffnung Flache, the Ludwig Flache and Ludwig Spat, the Abraham Spat and the Friedrich Spat, with the pyritic lead lodes. One square meter of vein surface sometimes contained rich silver ores having a value of several thousand marks.

A very typical development of barytic lead ore was also observed in the Tobias Flache, Hilfe Gottes Morgengang and Friedrich Flache, at the Segen Gottes Erbstolln at Gersdorf, near Rosswein, in Saxony. In these lodes, the crustified or laminated structure was found to be developed in wonderful perfection. Magnificent druses of fluorspar were often found, those of dark wine-yellow color being found in all large collections. This mine, which had good orebodies as late as the fifties, is at present idle.

Another Saxon district showing barytic lead veins is the zone 2-3 km. (1.2-1.8 miles) wide between the towns of Mittweida[1] and Oederan, a distance of about 24 km. (14.4 miles). They are mostly Spat and Flache lodes (see page 132), which here have united into a series. As late as the eighties mining continued in this region, being formerly quite extensive, on the right bank of the Zschopau, in the Alte Hoffnung Erbstolln, near Schönborn. The vein series traverses a body of schists intercalated among the granulites (gneiss, mica schist, biotite gneiss, cordierite gneiss, amphibole schist, alum slate, clay slate and quartzite slate), to a small extent also granulite and granite. The main lode, the Clementine Spat, strikes on an average north 60° west and dips northeast at 60-80°. Its thickness varies ordinarily between 1.5 and 2.5 m. (5-8 ft.), but in exceptional cases rises to 7 m. (22 ft.), where side stringers unite with the main vein. Quartz, fluorspar, barite and calcspar, with galena, pyrite, copper pyrite and gray copper, besides fragments of the country rock, form the main filling of the vein, the structure being unusually massive, but sometimes stratiform. The galena occurs in two varieties: coarse-foliated with

[1] H. Müller: 'Die Erzlagerstätten der Sectionen Mittweida, Frankenberg und Schellenberg,' Leipzig, 1881, in *Erlaut.* z. Sect. Frankenberg-Hainichen, pp. 84-120.

0.02-0.03% silver and fine-foliated (feinspeisig) with 0.05-0.10% silver. The high content of the latter is attributed to finely intermingled gray copper. The mining industry of Schönborn may be traced back to the twelfth century (Ermisch). In 1847 it was resumed, but has again been abandoned for a decade.

This mineral zone also includes the veins of Hilfe Gottes near Memmenderf, in the vicinity of Oederan, a typical specimen of which was shown in Fig. 129.

There are also transitions from the barytic lead veins to the barren barite veins, which are worked at several points in the Erzgebirge of Saxony, for example, near Aue.

As further German examples, we mention the lodes in the Münsterthale, in the southern Black Forest, described by A. Schmidt[1], especially the Shindler lode and the Teufelsgrund lode, as noted long ago by B. von Cotta[2]. Some lodes of the Kinzig valley, near Shapbach, also belong to this class.

On the Iberian peninsula this barytic lead type is found in the lode district of Hien de la Encina, in the Sierra de Guadalajara, between Madrid and Zaragoza, in a high mountain country built up of mica schist and gneiss. The gangue consists of barite, quartz and siderite. Among the ores, silver glance and other high-grade silver ores predominate to such extent that the habit of the deposit approaches that of the high-grade silver ore lodes[3].

The same transitions to the high-grade silver ore formations are exhibited by the very rich barytic lead veins in the mining region of Sarrabus, in the southwest part of the island of Sardinia[4]. The region is composed of Lower Silurian slates, abutting on the south against a granite mass, which has altered them by contact metamorphism. The lodes, which for the most part strike east and west, and traverse these schists, are for the most part developed as double veins. One may distinguish in them an older band, consisting of finely crystalline barite, some calcspar, quartz and coarsely foliated galena, poor in silver, associated with a little blende. The younger part of the lode forms a band of reddish, foliated barite, calcspar and fluorspar, with galena and blende both highly argentiferous, with

[1] A. Schmidt: 'Geologie des Müntserthales,' part II. 'Erzgänge und Bergbau,' Heidelberg, 1889.

[2] B. v. Cotta: 'Erzlagerstätten,' Vol. II, p. 177.

[3] B. v. Cotta: 'Erzlagerstätten,' Vol. II, p. 443. Fuchs and De Launay: 'Traité des Gîtes Minéraux,' Vol. II, p. 778.

[4] Traverso: 'Giacimenti a mineral d'argento del Sarrabus,' *Ann.* Mus. Civico, Genova, 1880-81, Vol. XVI, p. 493. De Castro: 'Descriptione et carta geologica de la zona argentifera del Sarrabus,' 1890. Fuchs and De Launay: 'Traité,' 1893, II, pp. 769-776.

brightly glistening fracture surfaces, together with native silver, horn silver, argentite, stephanite, pyrargyrite and proustite. Pyrite, marcasite, arsenopyrite, copper pyrite, molybdenite, as well as cobalt and nickel ores, appear merely as accessories. The lodes were first mined in 1622, but an active industry has existed only since 1870, and yielded rich returns in the seventies.

(ε) High-Grade or Noble (Edle) Silver Veins.

The lead veins connect by gradual transitions with those of the high-grade silver veins, in which the rich silver minerals, which in the first-named class were only occasionally present, decidedly predominate and impart to the veins their distinguishing character. It is possible to introduce some order into the chaos of phenomena, if the deposits are grouped according to their natural mode of occurrences. If, however, one follows the method adopted for other groups of veins, basing the division solely on the predominant matrix, we should be obliged to separate veins that belong together. We will therefore adopt a combined method, even though it is not consistent. Two groups, both of which are characterized by rich silver ores, will be distinguished by the prevailing gangue. Two other groups we will distinguish by the abundant presence of ores of a certain other kind, laying less stress on the matrix, because it is not always uniformly developed.

On this basis we may distinguish:

A. Veins with rich silver ores only, grouped as:

1. Those with quartz as predominant matrix, the *rich quartz formation*:

2. Those with calcspar as predominant matrix, the *rich calcspar formation;*

B. Veins with silver ores and other characteristic ores, grouped as:

1. Those in which many copper ores enter, with barite as the predominant gangue mineral, but frequently also with quartz and earthy carbonates; the *high-grade silver-copper veins.*

2. Those in which many cobalt ores, together with nickel-bismuth ores and uranium ores, are present, with quartz or carbonates forming the gangue; the *high-grade silver cobalt veins.*

Another group, the silver-gold veins, might have been added. It appeared, however, that the most prominent character of these veins is marked by the presence of gold, not silver, especially from an economic point of view. Hence, the silver-gold veins are not included here, but described with the gold veins proper. From what has been said it is apparent that the various types of rich silver veins admit of no sharp delimitation,

their frequent transitions to other very diverse types causing the distinction to become at times very faint. This will appear still more decidedly in the detailed presentation. In characterizing the different groups, advantage may also be taken of their geologic age.

12. High Grade Silver Quartz Veins.

These veins consist of ordinary white or gray quartz or hornstone, frequently showing a brecciated structure, with fragments of the country rock or of an older quartzose filling held together by later quartz. The ore minerals occur sprinkled through this matrix, in rather fine particles rarely united into bunches, nests, streaks or stringers. They are chiefly rich silver sulphides, such as silver glance, ruby silver, native silver, etc., but include argentiferous arsenopyrite and iron pyrite, more rarely argentiferous zinc-blende and galena. The mixture of ores ordinarily contains also a slight percentage of gold. Some departures from this prevailing character and some rarer ingredients will be enumerated and discussed in the several examples that follow.

The silver quartz veins of Freiberg in Saxony are first noted. According to H. Müller[1], the high-grade quartz veins are especially numerous to the north and west of the town, in the region of the upper gneiss (a microgranular biotite gneiss), and of the mica schist. The veins are grouped in an important series in a belt about 9 km. (5.4 miles) wide that extends from the region of the lower Muld valley between Hohentanne and Zella, near Nossen, in a southwest direction, for a distance of 22 km. (13.2 miles) across Bräunsdorf and Oberschöna, to the region of Oederan. The veins strike mostly between north-northeast and east-northeast and dip northwest. Their thickness varies between 0.1 and 1 m. (0.3-3 ft.) Some of them have been opened up to a distance of 2,600 m. (8,528 ft.) and for a depth of 460 m. (1,508 ft.) The general characterization given above applies with the following additions: Alongside of the principal quartzose matrix there are occasionally found subordinate amounts of ankerite, calcite and rhodochrosite. Besides the ores already mentioned, there are also found both ordinary and silver-rich tetrahedrite, miargyrite, stephanite, polybasite, freieslebenite, xanthocone, hydrostilpnite (3 Ag_2S, Sb_2S_3), alabandite, copper-pyrite, marcasite, capillary pyrite, stibnite, berthierite, kermesite, bournonite, zinkenite, jamesonite, etc. Arsenopyrite sometimes contains as much as 0.3% silver, iron pyrite up to 0.5 or even 1.2%, galena and zinc-blende usually still more. The zinc-blende is dark and "vitrified," that is to say, coated with films of argentite

or intimately overgrown with granules of argentite, giving it its high silver content. The pyritic and antimonial ores contain 0.5-8 g. per ton in gold. The ore minerals rarely form large compact bodies, being on the contrary for the most part in the form of fine dust-like particles scattered through the quartz. The silver minerals occur mainly as small parasitic crystals in small druses. The exceedingly fine distribution of the silver minerals in the quartzose matrix is exhibited in the reproduction of a thin section shown in Fig. 162, which is also of interest for the information it gives as regards the mode of treatment necessary for such ores. The lode structure is massive or breccia-like.

The most important veins of this series, and the ones most typical of the

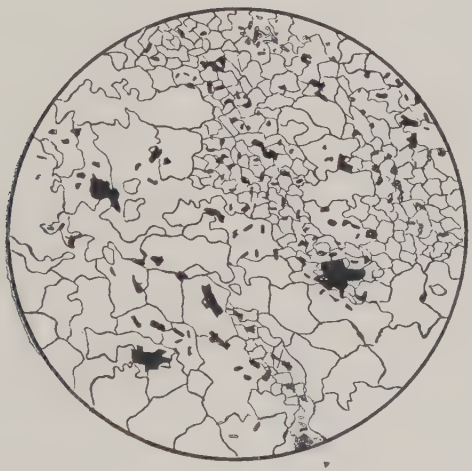


Fig. 162.—Thin section of gray quartz of Freiberg silver quartz veins, with fine particles of argentite and other high-grade silver minerals. (Enlarged 50 times.) (Outlines of quartz grains as shown in polarized light.)

formation, but no longer worked, are the lodes of the so-called 'Schwarze Gebirge' (black rock) of Bräunsdorf, a very irregular block of carbonaceous rock, resembling alum shale lying in the midst of the mica schist. Hence J. C. Freiesleben called the entire formation "the Bräunsdorf formation." In the black rock, according to H. Müller[1], the vast Neue Hoffnung Gottes Stehende vein, the main lode, from 300 m. (984 ft.) downward, becomes broken up into a series of smaller veins, such as the Verlorne Hoffnung Stehende, the Felix Morgengang, Aaron Morgengang, Jupiter Morgengang, Zweifler Stehenden, Augustus Spat, etc. All these veins, from 5 cm.

[1] H. Müller: 'Erzlagerstätten nördlich und nordwestlich bei Freiberg,' in B. v. Cotta's 'Gangstudien,' Vol. I, p. 174.

to 2 m. (0.1-6.5 ft.) thick, break up again into innumerable stringers. This whole network of stringers extends from northeast to southwest through the black rock, but only in rare cases does it send short branches into the adjoining mica schist. The most important ores of the Bräunsdorf lodes were what was there called 'Weisserz' (white ore), that is to say, a highly argentiferous arsenopyrite, ruby silver, miargyrite, native silver, stibnite, kermesite and berthierite. Beside the predominant quartz matrix, rhodochrosite, brownspar and calcspar appeared as accessories, in rare cases also fluorspar, barite, etc.

Somewhat farther to the southeast are the old mines of Oberschöna, one of which, the Zenith, was in operation as late as 1879-1893. Here, too, the typical high-grade silver quartz veins were mined.

The Bräunsdorf lodes are similar to the Peter Stehende vein of the Christbescherung mine near Grossvoigtsberg, which is still mined. Mention should also be made of the veins of Emanuel Erbstolln near Nieder-Reinsberg, Romanus Erbstolln and Vereinigt Feld near Siebenlehn, the last of which is still mined in a small way.

At the Gesegnete Bergmanns Hoffnung mine near Obergruna, which has recently been abandoned, all the veins, but more especially the Helmrich Spat and the Traugott Spat (see Fig. 126), are examples showing a slight variation from the type of the high-grade silver quartz veins. The ores are especially rich in argentiferous blende ('vitrified' blende, that is, coated with films of vitreous or earthy argentite) and galena, with pyrite, and also argentiferous arsenopyrite, which as 'coarse ore' are associated, even in the richer leads, with the 'high-grade ores' constituting the silver ores proper.

The lodes of the neighboring and still flourishing mine of Alte Hoffnung Gottes, near Klein-Voigtsberg, especially the rich main veins, the Peter Stehende and the Christliche Hilfe Stehende, are also not strictly rich silver quartz veins, but transition veins to the rich brownspar formation. Besides quartz, they carry much rhodochrosite, brownspar and calcspar, and besides the rich silver ores, much coarse matrix occurs. This mine is the only one of the veins of the Freiberg district proper which, thanks to its rich ore shoots, continues to pay working to the present day, despite the depreciation of silver.

Somewhat farther off from Freiberg one finds the typical rich quartz vein of the Friedrich August mine near Reichenau in the neighborhood of Frauenstein, which was in operation as late as the middle of the seventies. This, and the Emanuel Erbstolln near Drehfeld, were the mines which revealed the fact, so important in determining the age of the veins, that the rich quartz lodes are traversed by the Permian quartz porphyries.

Rich silver quartz veins also occur in the granulite (gneiss) formation of Rosswein, especially in the fibrous-uralite gabbro of Gersdorf and Wolfsthal, and again in the gneiss area near the Grossdorfhain and Höckendorf near Tharandt (Unverhofft Glück and Edle Krone mines), near Reichstädt and Ammelsdorf, in the vicinity of Dippoldiswalde, at all of which mining has ceased.

Rich silver quartz veins were also worked in former times in the neighboring regions of Bohemia, as at Nicklasberg and Klostergrab in the Bohemian Erzgebirge, at Adamstadt and Rudolstadt, northeast of Budweis.

Among the veins of the Kinzig valley in the Black Forest, this type is represented by those of the Morgen series.[1]

Numerous examples of rich silver quartz veins occurring in countries outside of Europe differ from the original Erzgebirge type in being of much younger age.

Where silver veins are associated with andesites and other Tertiary eruptive masses, as at Pachuca and Real del Monte, and where the ores contain gold even in small amounts, it is difficult to draw a distinction between veins of this class and those of the rich silver-gold ore formation.

Among the many known occurrences of this class those of Mexico probably claim the first rank. Most of the silver veins of that country[2] belong by their mineral composition to this division of the system into which we have grouped ore deposits. With few exceptions the predominant matrix of the Mexican veins is a crystalline quartz, often violet-colored, accompanied by subordinate quantities of calcite and rhodonite. In the zone of unaltered primary ores, they consist essentially of ruby silver ore, both proustite and pyrargyrite, accompanied at increasing depths by more and more gray copper, and finally also zinc-blende and pyrite, so that the richness slowly decreases. As regards the alteration products, there has been developed, directly above the primary ore, first a zone with simple silver sulphides, which usually contained the richest bonanzas, above this a second zone rich in chlorine-, bromine- and iodine-compounds of silver, and finally the gossan with native silver predominating, but usually of moderate richness (see gossan). These silver ore lodes traverse very diverse rocks. The famous Veta Madre of Guanajuato,[3] Mexico,[4] is probably the richest

[1] Vogelgesang: 'Geogn.-bergm. Beschr. des Kinzigthaler Bergbaues,' Carlsruhe, 1865, p. 9.

[2] Fuchs and De Launay: 'Traité des Gîtes Minéraux,' 1893, pp. 811-829.

[3] Visited in 1903 by W. H. W., who supplies description.

[4] 'Carta Minera de la Republica Mexicana por Antonio del Castillo,' 1893, Mexico. See also 'The Mineral Deposits of Mexico,' by Aguilera. *Trans.* Am. Inst. Min. Eng., Mexican Volume, 1903. C. Henrich: *Mining Magazine*, New York, 1904, Vol. VI, No. 1, p. 83.

silver-gold vein of the entire world, the production of the district, mainly from this one vein, reaching the enormous total of nearly $1,000,000,000. The vein occupies a well defined fault on the west slopes of a range of steep and barren mountains, composed mainly of well bedded volcanic tuffs with a capping of dacitic rocks and intrusive dikes of rhyolite. The andesitic tuffs, called sandstones by all earlier writers, are of varying colors and textures, mostly well bedded, but showing conclusive evidence in both field relations and in thin section under the microscope, of their origin by ejection, but in part sorted by water. These beds of andesitic tuffs rest upon micaceous schists and slates, cut by a mass of intrusive diorite, which altered the shale about it. The Veta Madre cuts through these earlier rocks, and at the south end through the tuffs, but so far as known does not cut the outflows and dikes of dacitic lava. The vein varies from a few feet to 50 feet across, widening in places to 120 feet. The ores occur in well defined shoots, the greatest—that of the Valenciana mine—being 1,400 feet long, 40 to 50 feet thick, and worked to a depth of 2,100 feet on the dip, or 1,750 feet vertical. The vein strikes northwest, and dips west with the mountain slopes at 45°. The vein filling between and alongside of the ore shoots consists of crushed and much altered country rock. The ore consists of quartz with orthoclase (var. valencianite) dusted and stained with minute specks of rich silver sulphide and rarely with pyrite. Galena is a rarity. The neighboring La Luz vein carries druses with remarkable crystals of apophyllite. The ores have averaged about 50 oz. silver for 350 years, but the rich oxidized and secondary sulphide orebodies run much higher. The ore shoots occur at and just beyond the intersection of the hanging-wall veins, coming in from the west, or La Luz system. At such points the vein is enormously thickened and the bonanzas occur. Earlier writers locate the richest ores at the points where the vein is crossed by ravines, and it is possible that secondary enrichment may have been particularly active at such places. The vein has a generally obscure outcrop, but is to-day traceable for seven miles by a very remarkable line of shafts and buildings.

Mining began at Guanajuato in 1558, and has continued with some interruptions ever since. Though in the last half century the production has come mainly from La Luz system, mining in the Veta Madre area has lately been very successful.

The lodes of Zacatecas and Fresnillo traverse similar conglomeratic porphyry tuffs, clay slates and calcareous shales, alternating with quartzites. At Catorce the veins occur in hornblende porphyrites. As these hornblende porphyrites are intruded in white Jurassic limestones with *Perisphinctes plicatilis,* the post-Jurassic age of the lodes is there established beyond doubt. We will dwell in somewhat greater detail on the

famous lodes of Pachuca and Real del Monte, situated north-northeast of the capital, abstracting from the official account published by the Geological Institute of Mexico.[1]

The mining area of Pachuca lies about 150 kilometers north-northeast of the City of Mexico in the region of the Sierra of the same name. Embracing an area of about 20 square kilometers, it is the largest and at the same time the oldest mining district of the entire republic. The Sierra de Pachuca, whose main strike is northeast-southwest, extends over a length of 43 km. and attains its greatest height in the northeastern part in the summit of the Cerro de las Navajas, 3,212 m. (10,536 ft.) The mountain range is traversed by numerous valleys, but only on the east slope are there any rivers that carry water throughout the year; they belong to the drainage area of the Rio del Amayac, a tributary of the Montezuma. According to Aguilera and Ordoñez, the Sierra de Pachuca owes its origin to a period of violent eruption, which apparently occurred in the middle Tertiary as a sequel to great dislocations. The latter led to the upraising of non-fossiliferous sediments, probably belonging to the Cretaceous. The products of those eruptions were, in the order of their age, andesites with their tuffs and breccias, rhyolites and their glassy forms, and, as last member, basalts. Dacites, too, were observed. The andesites, for the most part pyroxene andesites, sometimes diabasic in character, possess by far the greatest extent, and are of special interest, because they form the most widely distributed country rock of the lodes.

The latter may be divided into four groups, each of which embraces a main lode and several lateral veins. They comprise the Vizcaina, Cristo and Analcos lodes and of those of the Santa Gertrudis region. The strike of all these lodes is east-west, the dip, at a high angle, mostly south. The thickness, both in the strike and in depth, is subject to great change. Thus the Vizcaina lode at some points attains a thickness of 8 m., while that of the other parts of the lode varies between 0.3 and 6 m.

The matrix is, in the main, quartz, often developed as chalcedony; more rarely calcite, rhodonite and rhodochrosite occur. This explains why the outcrop of the lodes may often be traced far across the ground in the form of white crests. The lode structure is for the most part markedly banded, and only in isolated cases has a breccia structure been observed. A remarkable feature is a wide zone of decomposition along the selvages. The country rock, which often appears strongly silicified, has been found to be abundantly impregnated with pyrite at all depths. Part of it is also propylitized.

[1] J. G. Aguilera and E. Ordoñez: 'Mineral de Pachuca,' 1897. E. Ordonez y M. Rangel: 'El Real del Monte,' 1899.

According to the richness of the ore, three zones are distinguished from above downward:

1. *Metales colorados (podridos)* (red ore, rotten).
2. *Metales negros* (black) { (a) *Metales de pinta* (spotted ore). (b) *Metales de fuego* (fire ore).

In the first zone, that of the "colored or rotten ore," which owes its name to the prevailing iron and manganese oxides, silver chloride, bromide

Fig. 162*a*.—Cross-section of veins at Pachuca, Mexico.

and native silver are found, sometimes also native gold. This zone is considerably richer in gold than those which follow.

In the second zone (2a), fine-grained galena, argentite, pyrite and more rarely chalcopyrite occur.

The lowest zone (2b) contains galena, zinc-blende, pyrite, stephanite and polybasite. Some native copper, too, was observed. These ores, which are found but very rarely in definite crystalline forms, occur intimately

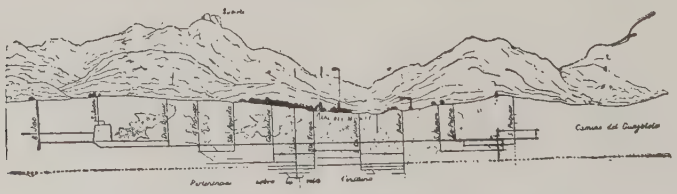


Fig. 162*b*.—Pachuca cross-section, continued.

intergrown with quartz. The presence of zinc-blende is unfavorable and indicates early impoverishment. Analysis has shown that the pyrite is always argentiferous, the percentage rising to 0.05%. The galena, too, is argentiferous, though not to the same degree, while the blende is almost always free from silver. Here, as in most of the silver lodes of Mexico, the occurrence of rich shoots, the bonanzas, is of the greatest importance in mining. It is not known that their occurrence is subject to any law, but they certainly begin only at a depth of 150 m. and seem on the whole to be normal in their course to the strike of the lodes. The size of these

bonanzas varies greatly; the greatest, encountered in the San Rafael mine, has a length of 1,000 meters.

Mining at Pachuca extends back to the time when the Aztecs obtained the ore by the aid of fire and stone implements. Immediately after the conquest of Mexico, the Spaniards began to exploit these rich mines, and, down to the eighteenth century, the Spanish Crown possessed the exclusive right of mining. The most famous mine at the beginning of that period was Xacal, which produced $7,000 worth of ore a day. After the war of independence the mines were sold to English companies (1824). After 28 years, however, these companies, burdened with debt, ceased operations, and the work was resumed only later and after the completion of railways, with Mexican capital. The production thereupon increased considerably, the San Rafael y Annexas company obtaining in eight years a gross return of $12,500,000.

Exactly similar conditions are found at Real del Monte, situated somewhat farther northeast of Pachuca. Mining operations were begun in 1578 and were formerly exceedingly remunerative. The work is mainly on three lodes: the Veta Vizcaina, 2 to 15 m. (6.5 to 48 ft.) thick, striking west-northwest and dipping south, extending over from Pachuca and opened up to a depth of 400 m. (1,312 ft.); the Veta Santa Inez, 40 m. (131 ft.) thick; and the Veta Santa Brigida, as much as 10 m. (32.3 ft.) thick, the two latter, striking north-south and dipping more or less steeply west and east, intersect the first named lode. All these veins have lenticular enlargements at close intervals, these ore shoots proving to be very rich in ore. These lenticular bonanzas coincide with those portions of the lode in which the dip is especially steep, almost perpendicular.

In the lower or deeper zones, to which working is now confined, at depths of 300 to 400 m. (984 to 1,312 ft.), the vein filling consists of quartz, often brecciated, and frequently associated with rhodonite and to a subordinate extent with calcite. The ores consist mainly of pyrite, copper pyrite, galena, in part argentiferous, and zinc-blende, together with argentite, polybasite and native silver. Druses studded with crystals of quartz, calcite, manganocalcite and rhodochrosite are common. In the upper part of the veins, on the contrary, the rich silver ores, especially ruby silver, exceed the pyritous ores in amount. The outcrop consists of a gossan rich in manganite, pyrolusite and wad.

Very commonly the country rock is pyritized or transformed into clayey masses, 'lamas,' or impregnated with pyrites.

The lodes of Real del Monte, too, are Tertiary beyond a doubt. The volcanic activity began in this region in the middle Miocene coincident with a strong folding of the Mesozoic strata, the earliest eruptive being

pyroxene-andesite. Next followed flows and dikes of rhyolite, in whose train the ore-bringing thermal waters rose. The next and last act of the volcanic period was an eruption of basalt, during which the vein fissures were in many cases fractured and displaced.

The period of greatest prosperity of Real del Monte was in the last two decades of the 17th century. From 1687-1697, La Trinidad mine alone is said to have yielded 40 million pesos. As late as 1759-1771, the mines of Real del Monte yielded to the principal owner at that time, Don P. R. de Terreros, $6,125,000. When mining became confined to the pyritous zone, the profit quickly decreased.

From what has just been said, it is doubtful whether Guanajuato, Pachuca and Real del Monte, with the other Mexican lodes mentioned, should be included in the rich silver quartz formation, since the ores contain from 20 to 30% of their value in gold, and have carbonates in the matrix. On the other hand, the association with rhyolites and andesites, the propylitization of the country rock, the participation of rhodonite as matrix, and the occasional gold content, establish a close similarity with Schemnitz. But for that matter, Schemnitz, too, as we shall see, does not represent a pure type, but constitutes a transitional form between the rich quartz and the silver-gold vein-types.

Another example of this class of veins occurs at Tonopah, Nevada, a district that has astonished the world by the richness of its bonanza ores. According to Spurr, the district is one of Tertiary volcanics, or sedimentary volcanic tuffs. The oldest rock is hornblende andesite, and still later rhyolite and dacite rocks occur, and the whole is cut into a complex system of blocks by faulting. The important veins of the region occur only in the early andesite, but four periods of hot-spring action and vein-formation are recognizable. The veins are linked veins, branching and reuniting both laterally and vertically. They are typical replacement veins formed along zones of fracturing. The primary ore consists of argentite, polybasite, and small amounts of chalcopyrite, galena blende and pyrite, in a gangue of quartz and orthoclase (valencianite). The rich ores occur in roughly defined shoots, with west-east pitch. These veins, though rich, are so cut by faults of different systems as to cause great trouble in working. The Mizpah vein, for example, is not only cut off east, west, and at the bottom by faults of great magnitude, but is broken up by minor fractures. The veins in the rhyolo-dacite rocks are characterized by a lack of persistence and definition. Bunches of high-grade ore sometimes occur in these usually barren veins, but only near andesite masses. The Goldfield veins, 23½ miles south of Tonopah, are similar, showing irregularly branching outcrops of pipes of jaspery quartz, the jackets about pay shoots of very rich

gold ores. In the past two years the district has produced ores to the value of $2,000,000.

A very rich development of the formation occurs at some points in Peru, in particular in the lodes of Quespesisa mine near Castrovirreyna in the department of Huancavelica, exploited during the last decades. The matrix there, according to the material furnished to the Freiberg collection by Mr. E. Treptow, is mainly a milk-white to glassy quartz, of distinctly crystalline, often drusy development, often colored dark gray by minute ore inclusions. This is found in association with subordinate amounts of a hornstone-like material composed mainly of chalcedony, only rarely of barite. The ores consist of pyrargyrite, polybasite and other rich silver ores, together with galena, fine-grained zinc-blende, a little chalcopyrite and pyrite. The rich portions contained on an average 2% of silver. The country rock is a strongly decomposed augite andesite.

The famous lodes of the Cerro de Pasco, in the Peruvian province of the same name, known from d'Achiardi's and Fuchs and De Launay's descriptions[1] may also be included with the rich silver quartz lodes, despite some aberrant features. At this place profitable silver mining has been carried on ever since the end of the thirties of the 17th century, despite the altitude, 4,352 m. (14,278 ft.), and the inhospitable climate. As late as 1879, 179 mines were in operation. The veins are of post-Jurassic age. The unaltered ores found in the deeper workings consist of highly argentiferous gray copper associated with galena in a gangue of quartz. In the upper zones, much pyrite and argentiferous copper pyrite are found, and at the very top, in the gossan, the rich secondary ores were found, which are here called *pacos* or *cascajos,* and contain an average content of 500 gm. silver per ton. The primary ore contains much copper and the district will soon be one of the great copper producers of the world.

Among the numerous silver veins of North America, those of Austin, Nevada, which, according to S. F. Emmons[2], occur in granite, and consist of a series of quartz stringers with pyrargyrite, proustite, polybasite, stephanite and tetrahedrite, and associated galena and blende, fit remarkably well into this category. Rhodochrosite and calcite occur together with the predominant quartz of the gangue. Some veins have been worked for stibnite. This occurrence is, therefore, completely analogous to the typical Braünsdorf or rich silver quartz lodes of the Freiberg area.

As an appendix to the discussion of the rich silver-quartz veins, mention may be made of a rare example, decidedly unique in its composition: a rich silver vein with quartz and orthoclase as gangue. According to

[1] Fuchs and De Launay: 'Traité.' II, pp. 829–832.

[2] S. F. Emmons: 'Fortieth Parallel Survey,' Vol. III, p. 349.

W. Lindgren,[1] the Black Jack-Trade Dollar vein occurs in granite, and in the basalt and rhyolite which rest upon it, at Silver City in southern Idaho. Where granite is the country rock, the vein filling contains orthoclase in addition to the more abundant quartz, and is often banded. The ores contain pyrite, copper pyrite and silver glance, enclosed in milk-white orthoclase, intergrown with quartz. This vein also contains druses lined with crystals of feldspar of the type called valencianite by Breithaupt, and first described from the Valenciana silver mine near Guanajuato in Mexico as noted in the description of that property.

13. Rich Silver-Calcite Veins (Rich Calcspar Formation).

Veins of this class consist mainly of calcite, sometimes colored dark by bituminous matter, together with quartz, fluorspar, zeolites and rarely axinite. Rich silver ores occur either finely disseminated through this gangue, or forming small pockets and short stringers. They comprise pyrargyrite, proustite, silver glance and native silver, more rarely dyscrasite (antimonial silver), arsenical silver, pyrostilpnite (fire blende), etc., usually associated with galena, zinc-blende, pyrrhotite, pyrite and native arsenic.

The veins are mostly thin and in large part scattered into stringers. The best known example of this class is seen in the veins at Sanct Andreasberg in the Harz, the following summary being based largely on the account given by F. Klockmann.

The Sanct Andreasberg[2] region is underlain by the Wieder slates, belonging to the so-called Harz formation of the lower Devonian, which contains many limestone layers, and holds numerous intrusive sheets of diabase. A little north of the mining area the Brocken granite forms intrusive bodies surrounded by contact zones of altered slates. The Andreasberg veins lie south of the contact zone of the granitic intrusive masses.

The veins are limited to a narrow wedge of rock, about 3 km. (1.8 miles) long and 1 km. (0.6 m.) wide on the east, but tapering westward. This block is bounded by two zones of faulting, viz.: the so-called Neufanger Ruschel at the north and the Edelleuter Ruschel at the south, as shown in the following sketch, Fig. 163, after F. Klockmann. These faults or "Ruscheln" meet near the Sieber river; eastward the network of

[1] W. Lindgren: 'Orthoclase a Gangue Mineral.' *Amer. Journ. of Sc.* 1898, Vol. V, p. 418. Also in 20th *Annual Rep.*, part III, Geol. Surv., Washington, 1900.

[2] Heinr. Credner: 'Geognost. Verhältn. Thüringens und des Harzes.' 1843. Also, 'Geognost. Beschreibung des Bergwerks-Distrikts von Sct. Andreasberg.' *Zeitschr.* d. d. G. G., 1865. C. Blömecke: 'Die Erzlagerstätten des Harzes.' Vienna, 1885, p. 48 *et seq.* F. Klockmann: *Berg u. Huttenwesen des Oberharzes.* Stuttgart, 1895, pp. 50–57.

veins extends geologically as far as the Oder valley. However, lodes of the same character also occur farther east, at Braunlage.

These delimiting faults are as much as 60 m. (186.8 ft.) wide, and consist of highly altered, leached and crushed rock, with alternating layers of harder rock, less affected by crushing, and consisting of layers of slate traversed by innumerable slips and planes of pressure and of slight movement.

The course of the northern fault corresponds approximately to the strike of the surrounding country rock, and may be conceived of as a system of overthrust planes, after the manner of the Clausthal lodes (see page 247). The Edelleuter Ruschel, on the other hand, cuts the strata at an acute angle, and the fault brings the slates against the diabase, the fault forming the boundary for some distance. This fracture is accompanied by two lesser converging faults, the Silberburger Ruschel and the Abendrother Ruschel. The two main fault lodes dip south 60 to 70°.

The Andreasberg veins are confined to the space between the main faults. Fissures do, indeed, occur beyond these limits, but they are of different character and filled with other ores and gangues. North of the Neufanger Ruschel the veins contain a quartzose red hematite filling, while south of the Edelleuter Ruschel the veins contain chalcopyrite in a barite filling.

Grouped according to their strike, the Andreasberg veins belong to two divisions. Those of the first group, for example the Fünf Bücher Moses series, the Samson lode, etc., strike northwest transversely to the faults (Ruscheln), and dip steeply northeast. They terminate against the fault-fissures by wedging out and breaking up into stringers. The others run approximately parallel to the faults, that is to say, between east-west and west-northwest, and dip north at 60-80°. They are deflected by the veins of the first group. The Bergmannstrost and the Gnade Gottes lodes are examples of this.

All the veins are in the main simple in structure, without stringers, and of but little thickness, usually between 1 cm. and ½ m. The filling consists mainly of compact, whitish calcspar (older calcspar generation), in which ores occur either as impregnations or in stringers and pockets and consist of galena, zinc-blende, native arsenic, proustite, dyscrasite, arsenical silver, native silver, rarely argentite. Here and there other minerals are seen, namely, antimony, and arsenious nickel (breithauptite and niccolite), cobalt pyrite, linnaeite, fluorspar and barite, as well as axinite as accessories. In numerous druses a second generation of the above named ores and gangues are found, particularly crystals of calcspar and ruby silver, in a great variety of forms with associated fireblende, antimony and numerous zeolites, such as apophyllite, analcite, harmotome, desmine,

stilbite, natrolite and sometimes also datolite. The distribution of the ores in veins is very irregular.

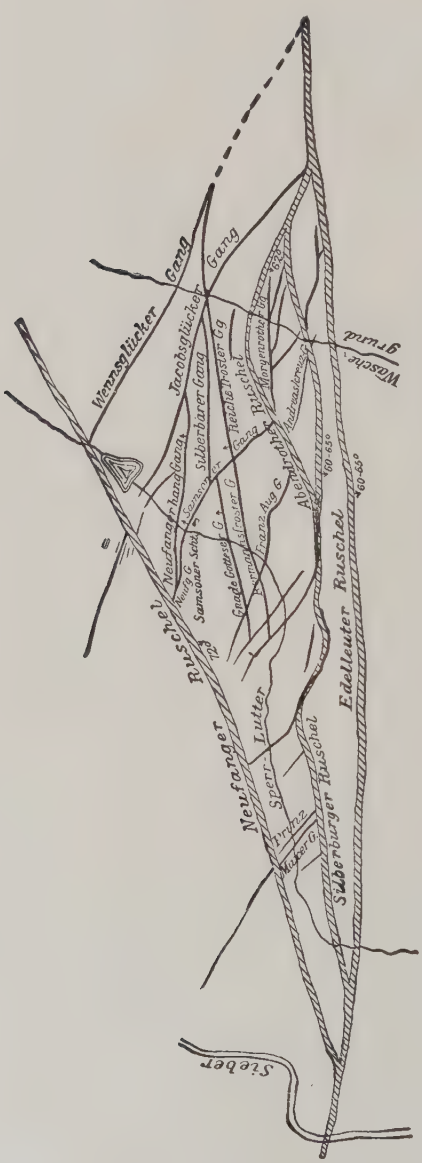


Fig. 163.—General plan of the Andreasberg lode area. (F. Klockmann.)

The Andreasberg veins were discovered in 1521 by Joachimsthal miners, who opened the first mine, called Sanct Andreaskreuz am Beerberg, so

christened, it is said, because two of the lodes intersected like beams of a St. Andrew's cross. The newly founded town was called by the name of the mine. The period of greatest prosperity was from 1565 to 1570. Though abandoned soon after that, work was resumed in 1646 and is in progress to this day.

A second typical representative of the rich calcspar formation is the group of veins at Kongsberg in southern Norway.

Kongsberg[1] lies in the southern part of the Numedal (southwest of Christiania), on both sides of the Laagen Elv. Most of the mines are situated about 6 km. (3.6 miles) west of the town, in a highly mountainous region, near the Jonsknut, 908 m. (2,978 ft.) high. The veins occur in steeply tilted crystalline schists, biotite schists, chlorite, talcose, quartzite and hornblendic schists as well as a garnetiferous biotite gneiss. These rocks are intruded by plutonic rocks near the ore deposits, as, *e. g.*, an olivine gabbro near Vinor, uralite gabbro and Flasergabbro (gabbro altered by pressure), at the Jonsknut, and norite at Skollenberg. In the Armengrube and the Kongensgrube, a dike of augite porphyry, a few decimeters thick, is known, which is cut by the veins and is but slightly displaced. In certain zones the foliated schists are impregnated with pyrite, which imparts to the weathered rock a rusty brown, or yellowish brown color, appearing gray when compared with the color of the normal schists. This led the German miners who founded the Kongsberg mining industry to call such zones 'Fahlbander' (gray bands).

Six bands of this sort are usually distinguished, whose aggregate thickness amounts to 300 m. (984 ft.) The pyrite is most abundant in the mica schist, less in the hornblende schist and is quite scanty in the gneiss. This impregnation with pyrite may be so abundant as to actually form compact layers of pyrite, as is seen in the pyrite pits of the Oberberg in the main fahlband of that locality. The distribution of the sulphides is always very irregular; the fahlbands may often enclose masses of rock entirely free from pyrite. The pyrite consists mainly of ordinary pyrite and magnetic pyrite, but includes copper pyrite, rarely cobalt glance (see the Modum occurrence). Fahlbands are also described as occurring in the gabbros.

[1] Most important publications: Böbert: 'Ueber den Kongsberger Bergbau.' Karsten's *Archiv.*, vol. XII, pp. 267–346, 1833. Report of Commission of Jahre 1865. Th. Kjerulf u. Tell. Dahll: 'Ueber den Erzdistrict Kongsberg.' Christiania, 1860. Th. Scheerer: 'Vorkommen des Silbers zu Kongsberg.' *Berg u. Hütten. Zeit.*, 1866, p. 25. C. F. Andresen: 'Om Gangformationer ved Kongsberg.' 1868. G. Rolland: 'Mém. sur la géologie de Kongsberg.' *Ann.* d. Mines. vol. VII, ser. XI., 1877, p. 301. Chr. A. Münster: 'Kongsberg ertsdistrikt.' Christiania, 1894. P. Krusch. 'Das Kongsberger Erzrevier.' *Zeit. f. Prak. Geol.*, 1896, pp. 93–104. J. H. L. Vogt: 'Ueber die Bildung des ged. Silbers, etc. und ein Versuch zur Erklärung der Edelheit der Kongsberger Gänge an den Fahlbandkreuzen.' *Zeit. f. Prak. Geol.*, 1899, pp. 113–123 and 177–181.

The pyrites of the fahlbands contain merely traces of silver. According to Chr. Munster, the pure pyrrhotite of a fahlband contained 0.0005% silver, besides 0.2% nickel and copper, while the pure pyrite contained only 0.0005% silver.

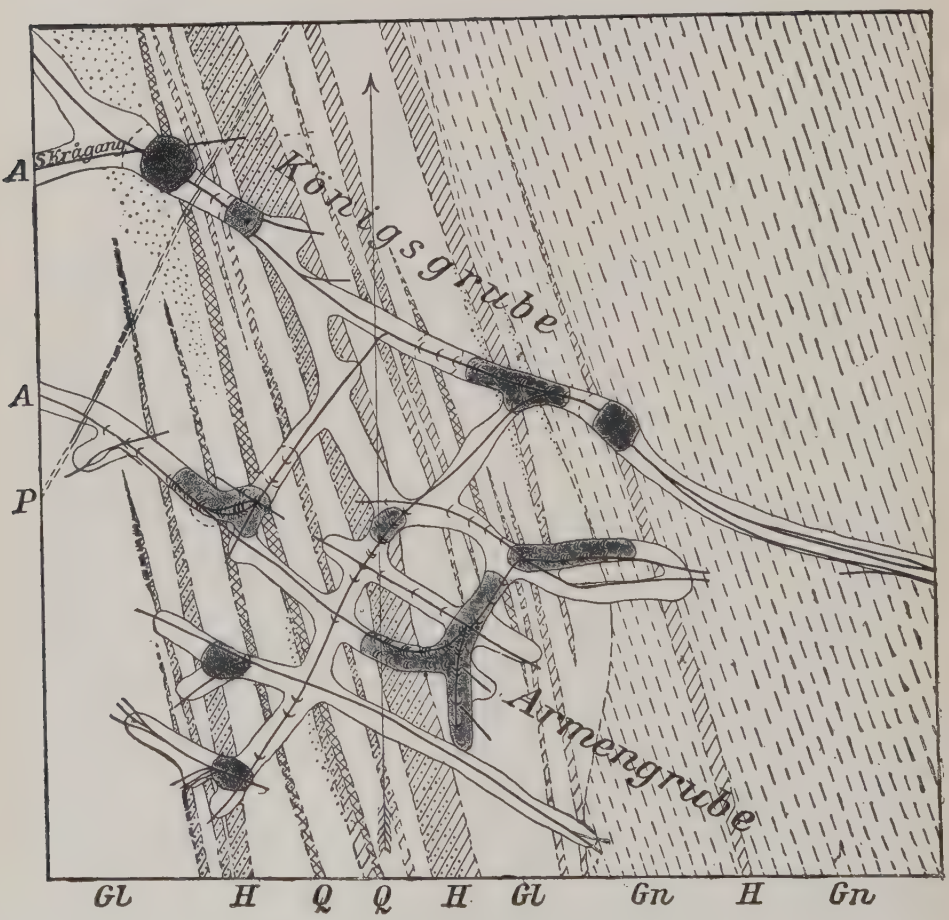


Fig. 164.—Ground plan of the 310 fathom level of the Armen mine and the Kongens mine at Kongsberg. (From the official plans.)

Gl, mica schist; H, hornblende schist; Q, quartzite schist; Gn, gray biotite gneiss (dots indicate development as fahlbands); P, dike of augite porphyry; A, drifts with lodes and orebodies (the latter shaded); (((rich, ((medium, (poor ores.

The Kongsberg veins are distinguished by their steep dip and their decided tendency to stringers. In various parts of the mine, several stringers, usually only 10 to 30 cm. thick, are worked simultaneously. This

is shown in Fig. 164, representing a portion of a mine map placed at our disposal by the administration of the mine. The longitudinal section, Fig. 165, also shows the same thing, and represents the distribution of the working drifts, not over a single compact lode, but over a series of stringers. The stringers may show local thickening, and in such cases may enclose druses of as much as 1.25 cubic meter in capacity.

The prevailing strike of the lodes is northwest. The main lodes are con-

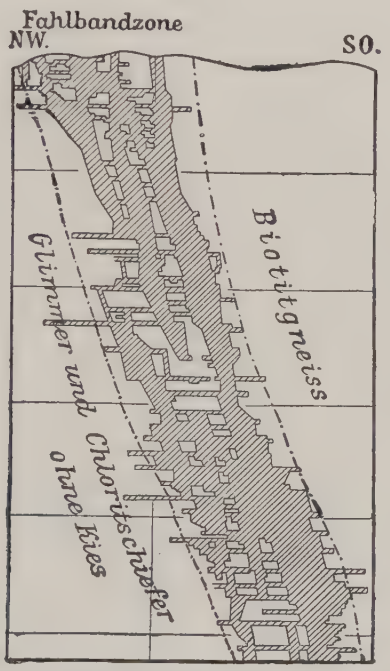


Fig. 165.—Horizontal plan of a series of vein stringers of the Kongens mine at Kongsberg. (J. H. L. Vogt.)

nected by a perfect network of diagonal and transverse stringers. All dip very steeply.

The predominant gangue is calcspar with lesser amounts of fluorspar, quartz and anthracite. Barite, axinite, albite, adularia and zeolites are rarities. The calcspar is usually colored brown by bitumen or coal. The ores consist in the main of native silver and silver glance. The native silver occurs as wires and points forming mosslike patches, as well as in large lumps of odd shape, especially fine specimens of which may be seen in the collection of the Royal Museum of Mineralogy at Copenhagen, collected

in the old days of mining. As late as 1867 there was found in the main lode of Kongens mine at a depth of 530 m. (1,738 ft.) a lump weighing 500 kilograms (1,110 lb.) consisting of silver with silver glance. J. H. L. Vogt has shown that the native silver is almost always younger than the silver glance, which is often coalesced with it. Sprigs and mosslike aggregates of silver often encrust the silver glance. Vogt thinks there has been an alteration of the argentite into native silver. Alongside of the silver glance is also found some ruby silver ore (proustite). The proportion of silver glance to native silver is about as 1 : 15. The Kongsberg native silver is often alloyed with other metals, especially quicksilver (up to about 1%) and antimony (up to about 0.6%). Silver amalgam, acanthite, hornsilver, and stephanite have also been found. These rich ores are often accompanied by pyrite, sphalerite, galena (with up to 0.05% Ag), pyrrhotite, copper pyrite, sometimes also arsenopyrite and cobalt ores, but pyrite is the only one found as a general constituent of the veins.

The ore shoots of the silver veins are confined chiefly but not entirely to the fahlbands, *i. e.*, where the veins traverse the pyritized gneiss. This local distribution of the ores is apparent from the longitudinal section of the vein series of the Kongens mine shown in Fig. 165. The output of silver in the fahlband zone is as a rule 0.2 to 4 kilograms to the square meter of lode surface, and is only exceptionally as much as 20 kg. (642 oz.) per square meter. At a little distance from the fahlbands, the veins are invariably barren.

In addition to the silver veins, younger, barren calcspar veins are known at Kongsberg; also quartz veins with chalcopyrite and bornite, which sometimes carry electrum (silver and gold). Neither of these two varieties of lodes is of any economic importance.

The Kongsberg lodes were discovered in 1623. The German names of the mines Gottes Hilfe, Armen Grube, Haus Sachsen, together with Kongens (Königs-) Grube, as well as the family names of many of the miners, recall the fact that Germans started this mining industry. In the Kongensgrube the work has now advanced to a vertical depth of 720 m. (2,260 ft.) The mines belongs to the Norwegian crown and continue to produce annually about 5,000 kilograms of silver. From 1623 to 1805 they produced about 543,000 kilograms of fine silver.

Very remarkable veins of this class characterized by rich silver-antimony ores occur east of Broken Hill in the Barrier Range of New South Wales. A vein occurs in the crystalline schists of that region which, wherever it crosses amphibolite intercalations, carries rich silver ores, namely the otherwise rare ores dyscrasite ($Ag_n Sb_m$), stromeyerite (CuAgS) and antimonious silver chloride, besides gray copper, in a gangue of calcite and iron

spar[1]. These ores occur in rich bunches associated with clayey material. Cobalt ores play a subordinate part.

14. Rich Silver-Copper Veins.

The veins of this class consist of rich silver and copper ores in a barite gangue, carrying quartz in the deeper levels, with associated zeolites and carbonates. The rich silver and copper ores are generally associated, especially in the deeper levels, with rich gray copper and pyrite-blende ores, and cobalt and nickel ores as mere accessories[2]. The rich silver-copper veins occur most often in basic plagioclase-augite rocks, especially augite porphyries, or at any rate within sediments of Mesozoic age traversed by those rocks. This is especially true of the Chilean occurrences described by W. Moricke[3] at Tres Puntas, Cabeza de Vaca, Los Bordos, Chañarcillo, San Antonio, and Caracoles, all in the region of the Atacama desert, as well as those of Arqueros in the province of Coquimbo.

Only a few of the best known examples can be described in detail.

Chañarcillo[4] lies about 80 km. (48 miles) south of Copiapo, the most important town of northern Chile. The prevailing rock is a gray-blue or dark gray limestone of Upper Jurassic age. This limestone is cut by numerous dikes and intrusive sheets of augite-porphyrite accompanied by contact zones rich in calcium-silicates. These rocks are themselves cut by numerous veins, mostly striking north-northeast. The best known veins are the Corrida colorada, Guias de la Descubridora (a network of stringers in the Lorete mine; Guia = guide-streak), Guias de Carvallo, Mercedes vein, the Candelaria vein, whose strike, by way of exception, is east-northeast. The Corrida colorada has been found to carry rich ore to a depth exceeding 600 m. (1,968 ft.), and has been traced over a distance of 1,800 m. (5,904 ft.) horizontally, with a thickness of 10 m. (32.8 ft.) in the upper regions, only 1 m. (3.2 ft.) in the lower. At the north it is cut off by a great fault. The veins in the upper levels carry native silver, silver chloride, silver bromide and malachite, besides brownspar, calcspar and barite. These ores lie in a clayey gangue colored yellow by ferric hydrate; farther down they carry

[1] G. Smith: *Trans.* Am. Inst. Min. Eng., Vol. XXVI, 1897, p. 69.

[2] On account of the predominance of barite, it might seem natural to use the term "rich barite formation," which would be very appropriate for many cases, especially in Chile, and would moreover be more consistent with preceding categories, but the occurrences at Huanchaca and Huancavelica, though closely related to the others, yet almost or entirely free from barite, would then have no place. Hence the above designation, first used by W. Moricke, was chosen.

[3] W Moricke: 'Die Gold- Silber- und Kupfer erzlagerstätten von Chile.' Freiberg, 1898, p. 27.

[4] Fr. Moesta: 'Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen des Silbers in der Natur.' Marburg, 1870, p. 15.

native silver, argentite, polybasite, proustite and pyrargyrite; still deeper, increasing amounts of blende, galena, arsenopyrite and a little pyrite. In crossing certain beds (porphyrite sheets), not only are the veins themselves enriched but they have also impregnated these adjoining rocks with valuable ores. The enriched beds adjoining the vein are called *mantos pintadores*. The impregnation is especially strong in the hanging-wall of the lodes and in the upper levels. It is often associated with silicification. Such enrichment may also be observed at the points where the augite-porphyrite dikes (the so-called chorros) cross.

The lodes of Chañarcillo were only discovered in 1832 by the Indian Juan Godoi, and soon became famous because of the fabulous wealth of their outcrop. The mines yielded a very large silver production until very recently.

A similar reputation is enjoyed by the mining district of Caracoles (meaning "snails") in northern Chile, north of Antofagasta in the Atacama desert. Highly fossiliferous Upper Jurassic marls and limestones, whose fossil ammonites gave the name to the mine, are cut by intrusive masses of quartz porphyry and augite-porphyry. The silver veins are said to be much richer in these porphyries than in the limestone. The veins carry ores similar to those at Chañarcillo, in a matrix consisting essentially of barite and calcite. Argentite, proustite, pyrargyrite and highly argentiferous galena are common, while in the upper depths several kinds of silver chloride and bromides occur with native silver.

The veins have only been known since 1870. According to an estimate by Domeyko they produced in the best years 120,000 kilograms of silver.

Similar conditions prevail at Arqueros in the province of Coquimbo. Upper Jurassic limestones, broken through by porphyries, are traversed by barite veins rich in native silver, amalgam, silver chloride, stephanite, gray copper, cobalt pyrite and copper pyrite.

In the adjoining republic of Bolivia, the copper-silver veins also contain lead. The veins of the region of Huanchaca in the province of Potosi are most interesting. Among the various mining fields of this region, Pulacayo, Ubino and Asiento—the first named in particular—have become famous during the last few decades by a large production, and the mining operations, begun by the Spanish conquerors at an early date, and afterward long abandoned, have recently been extensively resumed.

The lodes of Pulcayo[1] occur in trachytic and andesitic rocks. The main lode, striking east-west and 1/3 m. thick, has been opened up to a distance of 1,100 m. (3,608 ft.) in the strike, and to 500 m. (1,640 ft.) in the dip. In

[1] A. Gmehling: 'Huanchaca.' *Oesterr. Zeitsch.* f. B. u H., 1890, p. 281. Fuchs and De Launay: 'Traité,' Vol. III, 1893, p. 852.

the upper depths it is said to have shown a great resemblance to the Chilean examples of the rich silver-copper formation, and, like them, to have been characterized by barite and rich silver minerals, together with gray copper. With increasing depth, quartz with a little calcite took the place of barite. Finally, in the lower workings, according to A. Gmehling, the proportion of barite to quartz was 0.5 : 21. At the same time the rich silver ores were replaced by a mixture of metallic minerals, which, according to the same author, consisted, as stated in the relative order of quantity, of zinc-blende, with 0.2% and more of silver, pyrite, copper pyrite with about 0.3% silver, and galena with an average of 0.6% silver, a mixture whose real value was derived from the presence of tetrahedrite with as much as 10% silver. This gray copper often occurred finely crystallized in druses associated with quartz. In rare instances radial aggregates of stibnite are observed. Mention should also be made of a small content of gold, tin and bismuth in the various ores, while large masses of white lithomarge, with inclusions of gray copper, also occur in the vein filling.

In 1893 the Huanchaca mines produced 281,006,924 kilograms of silver. In 1898 it was only 144,049,443 kilograms, 51,500 tons of ore being exported.

The same type of lode is found in Peru, in the department of Huancavelica, for example, the mines of Morlupa and Julio Caesar, whose ores at some depth consist mainly of a mixture of gray copper, chalcopyrite and galena, in a gangue of quartz and carbonates. Sometimes, as in the case of the Caudalosa mine in the department of Vuitava, there is found a mixture of gray copper, red zinc-blende, famatinite (Cu_3SbS_4), antimony glance and realgar, with quartz and barite.

The occurrence of famatinite associated with enargite (Cu_3AsS_4) also characterizes many veins in the Argentine Republic. Such veins were described by A. W. Stelzner[1] at the Cerro de Famatina in the province de la Rioja. They occur in clay slate broken through by intrusions of dacite and andesite. Rich silver ores occur but very scantily and the ore deposit has the character of a copper formation. Besides enargite, which is decidedly the prevailing ore, the veins also carry famatinite, pyrite, copper pyrite and zinc-blende, with a little proustite, in a gangue composed of quartz, hornstone and barite. The mines are now worked mainly for copper. The Mejicana, Upulongos and Capillitas are the best known.

In the Old World, this type of copper-silver vein, so widely prevalent in South America, presents conditions of a widely different nature. It is probably developed in the remarkable silver mines of Smeinogorsk or

[1] A. W. Stelzner: 'Beiträge zur Geologie der Argentin. Republ.' 1885. Vol. I, pp. 216, 232.

Schlangenberg (snake mountain) in the Altai Mountains of Siberia described by B. von Cotta[1].

The mines lie in a region of Paleozoic rocks, traversed by porphyries and porphyrites. At Snake mountain, there is a vast interbedded ore deposit which expands locally into the form of a stock in the midst of these strata. It is composed essentially of barite and some quartz, and contains rich silver ores, such as native silver, silver chloride, argentite, proustite, miargyrite and highly argentiferous gray copper, as well as some native gold, together with copper ores, such as glance, copper pyrite and secondary copper ores, as well as galena, pyrite and zinc-blende. The footwall consists of a fossiliferous Devonian hornstone, swarming with stringers of ore-bearing barite, and representing perhaps a silicified limestone. The hanging consists of clay slates of the same formation. The mass of the vein, which is still found here and there to be 20 m. (65.6 ft.) thick, and is said to be still thicker at the outcrop, may be divided into five streaks, defined by the richness of the ore; the uppermost consisting of pure barite and containing but little silver; the second, a mixture of baryta carrying silver ores as very fine dust; the third, a mixture of ore-bearing barite and hornstone; the fifth consisting of hornstone traversed by ore-bearing barite veins; and, finally, the hornstone of the footwall, which is devoid of ore. The deposit is traversed by porphyrite dikes, 1-3 m. thick.

The mineral veins of Smeinogorsk, which were worked by the Tschudes in prehistoric times, were rediscovered in 1742, and have since then been imperial crown land, being worked with varying success.

15. Veins of Rich Silver-Cobalt Ores.

In this type of vein, the gangue is not everywhere developed in the same way. In one variety, seen at Joachimsthal, Austria, it consists mainly of quartz, hornstone, calcspar and dolomite; in the other, as at Annaberg, barite and fluorspar are added to the first named minerals. The ore minerals, on the contrary, are everywhere uniform in occurrence, consisting of cobalt, nickel and bismuth minerals, as well as uranium ores, which usually occur associated with the non-carbonate gangues that form an older part of the lode filling; also of rich silver ores, which are wont to represent a younger generation. These veins belong to the older geologic formations. In the Erzgebirge they are found about the borders of granitic

[1] B. von Cotta: 'Schlangenberg-Silbergrube im Altai.' *Berg u. Hutten Zeit.*, 1869. No. 28. Also, 'Der Altai.' Leipzig, 1871, p. 192. C. Griwnak: 'Les gisements de minérais dans l'Altai.' *Journ. d. Min.*, 1873, Vol. II, No. 5, 6, pp. 172-265; 1875, Vol. II, No. 6, pp. 277–311. (In Russian.) G. Mayer: 'Les mines d'argent de l'Altai.' *Compte-rendu* du Conseil de la Soc. Amat. Investig. d'Altai, 1891–1893, p. 31.

intrusive masses of late Paleozoic age, with which they are genetically connected. They are traversed by Tertiary basalts. Analogous veins found at other localities and of similar age are of no economic importance, as compared to the Erzgebirge.

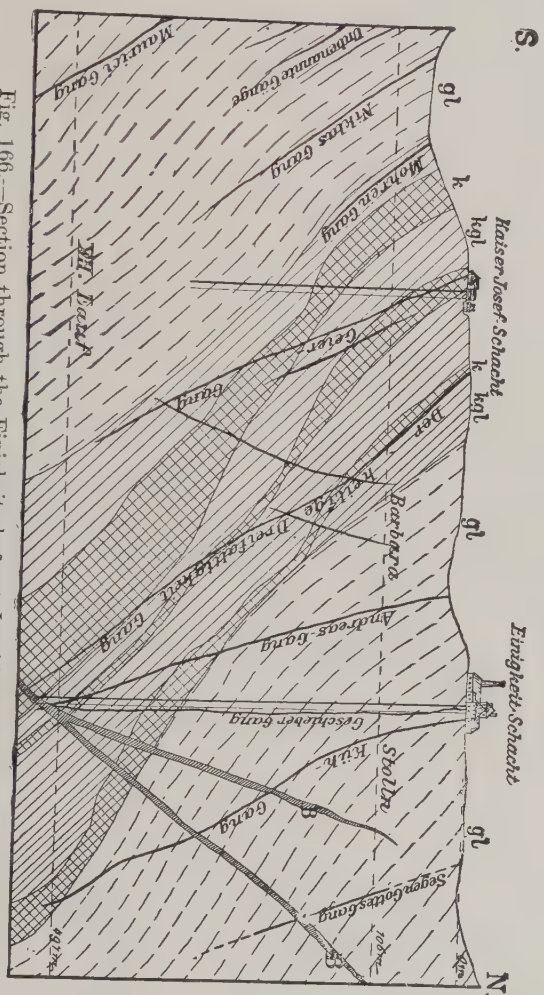


Fig. 166.—Section through the Einigkeit shaft at Joachimsthal. (F. Babanek.)
gl, slaty mica schists (phyllites); kgl, calcareous mica schists; k, limestones; B, basalt.

For our first example of this formation we will select Joachimsthal, Bohemia, where at the present time mining operations are confined to veins of this type.

The Joachimsthal district lies on the higher southern slope of the Erzgebirge, southwest of its highest elevation, the Keilberg, 1,238 m. high,

near the Saxon boundary. The rocks are mica schists, with east-west to westnorthwest foliation and north dip. In the vein area finely crystalline, slaty mica schists predominate, with intercalated layers of calcareous mica schists, crystalline limestones and coarse-fibered mica schists. (See Fig. 166.) Toward the northeast and east gneisses occur, while toward the southwest the schist ends abruptly against granite, the northeast contact of the great Eibenstock-Karlsbad massive of tourmaline granite, which crosses the axis of the Erzgebirge. At its border a contact zone is developed, which, however, does not quite extend into the Joachimsthal mineral vein area. Numerous dikes of quartz porphyry, sometimes quite large and running northwest to north-northwest, traverse both the region northeast of the

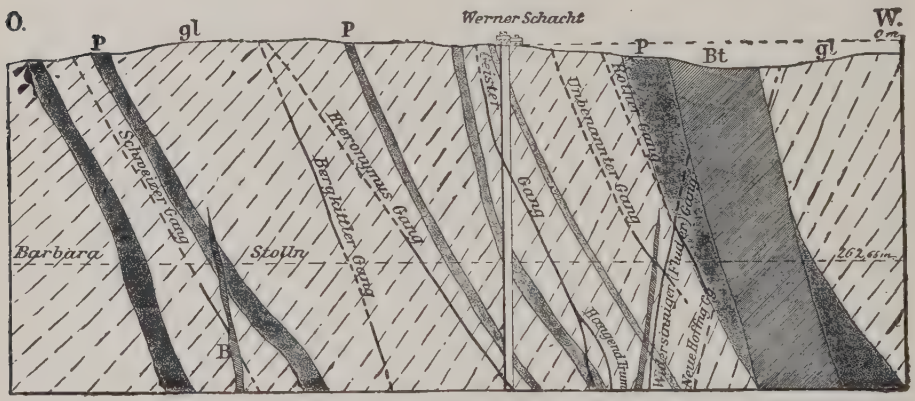


Fig. 167.—Section through the Werner shaft at Joachimstahl. (F. Babenek.)
gl, mica schist; P, quartz porphyry; B, basalt; Bt, basalt tuff (Putzenwacke)

granite, and the mineral area. Dikes of basalt and phonolite, as well as bosses of these rocks, were intruded in Tertiary time. The tremendous earthquake shocks that must have taken place during that period have left their record in wide fissures extending deep into the rocks, which must have remained open for long periods, since volcanic, phonolitic and basaltic material, together with silicified deciduous trees, that is to say, débris washed from above, were found in the Joachimsthal deep levels within the so-called *wacke lodes* in mica schist, particularly in the Barbara drift, at a depth of 262 m. (859 ft.) (See Fig. 167.) This remarkable fact was mentioned as early as 1557 by Mathesius, the preacher miner and reformer of Joachimsthal.

According to their strike, the silver-cobalt veins of Joachimsthal,

especially those close to the town on the northwest, fall into these two groups:

(a) Morgengange, striking eastnortheast (7 hours) and dipping north at 60-80°; (b) Mitternachtgange, striking northnortheast to northnorthwest, for the most part, almost exactly north-south (11-1 hours) and dipping at times 45-85° west or east.

Some of the lodes of the first group, for example, the Geyer and Mauritius veins, were very rich in the upper levels, but grew poorer in depth, so that they became of little importance in the modern mining period. On the contrary, some of the veins of the second group have in recent decades been worked by deeper drifts with success, particularly the Geistergang, which showed fine bodies of silver ore, especially in 1853; also the Rothe, Prokopi, Anna, Geschieber, Hildebrand, Junghäuerzecher and the Evangelisten veins.

The width of the veins varies between 15 and 60 cm. and only exceptionally reaches 1-2 m. (3.28 to 6.56 ft.) Stringers are common. Some of the Mitternacht veins reach the surface not as true veins, but as narrow, barren cracks[1].

The filling is not the same in all the veins. Thus in the western Mitternachtgänge it is for the most part a brittle clay, with quartz and hornstone; in the eastern veins it is mostly calcspar and dolomite, while both sets of veins occasionally show a brecciated structure. The ores in these gangues form stringers, branches and pockets that are very spotty. According to G. Laube, these ores may be divided into:

1. Silver ores (native silver, argentite, polybasite, stephanite, tetrahedrite, proustite, pyrargyrite, sternbergite, argentopyrite, besides rittingerite, acanthite and cerargyrite).
2. Nickel ores (niccolite, chloanthite, millerite).
3. Cobalt ores (smaltite, as well as bismuth-cobalt-pyrite and asbolate).
4. Bismuth ores (native bismuth, as well as bismuth glance and bismuth ocher).
5. Arsenic ores (native arsenic, arsenopyrite).
6. Uranium ores (pitchblende).

Galena, zinc-blende, pyrite, marcasite, copper pyrite and bornite only occur subordinately and occasionally. Among these ores, the cobalt and nickel ores appear to be on the whole the older, the silver ores the younger. From the numerous sections of the lode published by F. Babenek, we have chosen the one shown in Fig. 168, which exhibits the characteristic distribution of ores and gangues.

[1] Compare with W. P. Jenney: 'Mineral Crest,' *Trans.* Am. Inst. Min. Eng., Vol. XXXVII, p. 46; discussion, p. 1060.

Near the lode fissures, the country rock frequently has been impregnated with extremely finely divided ore particles. This explains the small percentage of metals shown by F. Sandberger and A. Seifert to exist in various rocks of Joachimsthal, especially copper, cobalt, nickel and arsenic. In like manner the presence of minute granules of uranium pitchblende in a scapolite-mica-schist of that locality, first discovered by F. Sandberger and conclusively confirmed by F. Babenek and A. Seifert,

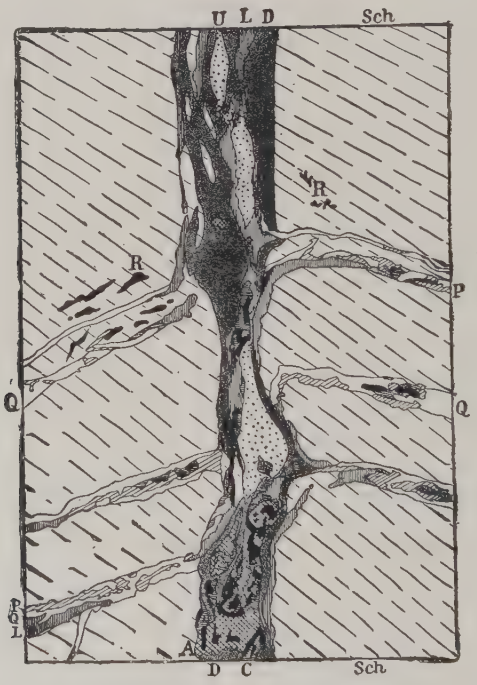


Fig. 168.—Cross-section of the Hildebrand lodes at Joachimsthal. (Babanek-Nemecek.)
Sch, schist; D, dolomite spar; C, calcite; Q, quartz; L, vein-clay; R, pyrargyrite; U, pitchblende; A, argentiferous arsenic ore; P, pyrite. The vein crosses three old lodes with quartz filling.

by means of large-scale ore concentration experiments, is most naturally explained by an infiltration from the lode fissures. Their presence as primary constituents seems to be gainsaid by their very unequal distribution in the rock. In the experiment just noted, the dressing of 6,358 kg. from a richer zone gave 226 kg. of concentrates with a content of 0.3% of uranic binoxide.

The veins traverse dikes of quartz porphyry, and in their turn are cut across by dikes of basalt and the *wacke* veins. However, since these *wackes* sometimes contain some interspersed argentite (earthy silver glance) where they cross the ore veins it is inferred that at the time of the eruption of the younger volcanic rocks the vein formation had not yet been quite completed. It may also be mentioned here that in 1864, according to Fr. Weselsky, a spring with a temperature of 23° Reaumur (84° F.) was tapped on the Geschieber lode at a depth of 531 m. (1741 ft.)

At the acute-angled lode crossings there has been an enrichment of the ore. The veins are richer in the porphyry and to the east in the limestone intercalation than in the schist.

The Joachimstahl mining industry began, according to G. Laube, at the end of the 15th or in the early years of the 16th century. As early as 1517 a mining settlement existed in the valley, and as early as 1518 the first "Joachimsthaler" were minted, this coin being now known as the thaler. In 1520 the settlement obtained the privilege of a free mining town. The total output for the first 44 years is put at 40 tons of gold, that is to say, over four million gulden, reckoning silver at the value prevailing at that time. After 1545 the industry suffered a great decline, but acquired new vigor when the cobalt and bismuth ores became valuable. In recent time the industry has languished because of the depreciation of silver. During the last decades, special attention has been paid to the extraction of uranium, for which a government factory has been set up at Joachimsthal. In 1898, 50.9 tons uranium ore was obtained[1].

Conditions similar to those of the Joachimsthal lodes were found to prevail on the Saxon side of the Erzgebirge in the silver-cobalt veins of the vicinity of Annaberg, described in the detailed monograph of H. Müller[2].

In this vein area the rock consists mainly of gray gneiss (the "bimicaceous principal gneiss" of the geologic map). The district forms the southwest part of the Annaberg-Marienberg gneiss dome. In this dome, at the southwest periphery of the area, at Buchholz, a granite stock is exposed, from which a tongue of fine-grained granite (porphyritic microgranite) runs through the mineralized district northeastward in the form of a dike. Similar smaller dikes of this rock have been met with at

[1] Some of the more important publications upon Joachimstahl are: G. Laube: 'Aus der Vergangenheit Joachimsthals,' Prague, 1873. Also, 'Geologic des böhmischen Erzgebirges,' Prague, 1876, p. 176–192. F. Babenek: 'Ueber die Erzführung der Joachimsthaler Gange.' *Oesterr.* f. B. u. H., 1884, pp. 1, 21, 61. Also, 'Die Uranhaltigen Skapolith-Glimmerschiefer von Joachimsthal,' 1889, p. 343. Also, Geologic. bergm. Karte mit Profilen und Bildern von den Erzgangen in Joachimsthal.' Published by the Imperial Royal Ministry of Agriculture, 1891.

[2] H. Müller: 'Die Erzgänge des Annaberger Bergrevieres.' Geolog. Survey. Leipzig, 1894.

several points above ground and underground. At the northeast edge of the field, at Wiesenbad, in the valley of the Zschopau, the erosion of the river has laid bare an intrusive stock of granite, so that this rock may be presumed to be rather widely distributed in the deeper levels of the mining area. Furthermore, mining operations very frequently encounter narrow dikes of lamprophyre (fine-grained mica syenites and mica diorites), at times also basalt dikes. The latter are genetically connected with the sheet of leucite basalt, which resting on a substratum of fluviatile clays, gravels and sands of the Oligocene, forms the tomb-shaped Pöhlberg immediately southeast of Annaberg.

More than 300 veins traverse the rocks near the town and in the district about it. They may be divided according to age into two groups. Of the older, it may suffice to mention briefly the tin lodes of the former Alte Thiele Fundgrube near Buchholz and the pyrite blende lead veins, which, because of their unusual richness in copper-pyrite and other copper ores (see page 238), were worked in the Sanct Briccius, Heilige Dreifaltigkeit, Weinkeller, Rothe Pfütze and Spanier mines on the east slope of the Pöhlberg and at several other points. The strike of these veins is usually about east-west. They have always proved to be younger than the lamprophyres, but older than the basalts.

On the other hand, the younger group consists of the silver-cobalt veins, in which we are here especially interested, and of examples of the iron and manganese veins which are developed farther southwest, in the region of Scheibenberg.

The silver-cobalt veins are the most important ore deposits of the Annaberg field. Besides those of the Annaberg district itself, the only one which we will here consider, there are others at Schmalzgrube and Steinbach in the Pressnitz valley, at Jöhstadt, at Bärenstein and Weipert, and at Oberwiesenthal, where they form a transition to the great Gottesgabe-Joachimsthal mining field, and a sixth area near Scheibenberg. In all these fields, mining is no longer carried on.

The silver-cobalt veins occur in two principal series, whose directions intersect at nearly right angles. Most of them strike northnorthwest, a less number strike eastnortheast to east-west. Only a few have a diagonal strike of north-south to northnortheast. The northnorthwest veins belong exclusively to the silver-cobalt class; the veins of other courses are in part of different characters and age. The veins of the northnorthwest series have usually a steep dip, those of the east-west series have a dip of but 45-60° in different directions. Most of the veins have been followed for a horizontal distance of 800 m. (2,624 ft.), some much farther, the Treue Freundschaft Stehende at least 2 km. (1.2 miles). On the other hand,

mining operations on these lodes have penetrated to no great depth, the deepest, about 400 m. (1,312 ft.), being in the Erstneuglück Flachen and the Heynitz Flachen. The thickness varies between 10 and 20 cm., in exceptional cases amounting to 2 meters (6.5 feet).

The vein filling consists mainly of barite, fluorspar, quartz and brownspar with various cobalt, nickel and bismuth ores, especially chloanthite, smaltite, gersdorffite, annabergite (nickel-ocher) and native bismuth, rarely bismuthinite, rich silver ores, especially pyrargyrite, proustite, argentite, earthy silver glance, native silver, silver chloride, and finally pyrite. The subordinate gangue minerals include hornstone, chalcedony, amethyst, calcspar, aragonite, kaolin, lithomarge, gypsum; among the ores, copper pyrite, galena, zinc-blende, marcasite, gray copper, siderite, uranium pitchblende, uranochalcite, gummite, zippeite, native arsenic, with others of minor interest.

An interesting feature of the vein is the occurrence in former times of great masses of silver chloride; for example, in the 16th century, in the Himmlisch Heer vein, masses of pure horn-silver were found as much as 20 pounds in weight.

The veins are frequently filled with fragments of country rock and the brittle inter-vein rock and attrition clays. Argentiferous vein clays have sometimes been mined. The prevailing structure of the vein filling is irregularly massive.

According to H. Muller, the result of more than 200 observations showed as a rule a definite succession in the deposition of the minerals of these Annaberg silver-cobalt veins, which he summarized as follows:

V. Decomposition products such as annabergite and cobalt efflorescence.
IV. Rich silver ores and native arsenic.
III. Calcspar and uranium pitchblende.
II. Brownspar and cobalt-nickel-bismuth ores.
I. Barite, fluorspar and quartz.
I and II together always form the bulk of the filling.

As already stated, the silver-cobalt veins cut through the tin-bearing and pyritic lead veins, as well as the dikes of microgranite and lamprophyre. The basic dykes are often accompanied by silver-cobalt veins. Thus the Heynitz Flache vein follows a lamprophyre dike 0.1-3 m. thick, for almost 600 m. along its strike and to a depth of 340 m. It follows first one wall, then the other, and in places crosses the dike. On the other hand, both this and other examples of this type of vein are cut across by basalt. The basalts encountered in the mines not only form true dikes, but also occur as vertical chimneys or pipes of round cross-section. As rich silver ores

occasionally occur interspersed in fissures in the midst of the basalt mass near vein crossings, as at Oberwiesenthal, it is inferred that chemical transpositions of the metallic compounds took place even later on.

The various relations of veins and eruptive dikes are illustrated by the accompanying Fig. 169.

An important feature in the mining industry of Annaberg is the presence of the so-called "Schwebenden," that is to say, sheets of decomposed rock ordinarily parallel to the foliation of the gneiss, but sometimes also transverse to it. These sheets are from 1 cm. to 2 meters thick, are ordinarily colored blackish by fine earthy, carbonaceous substances, and often contain finely interspersed pyrite and sometimes copper pyrite. As indicated by their name, they are distinguished by a flat dip. The "obere Schwebende," of the Markus Rohling Fundgrube at Schreckenberg, dips in

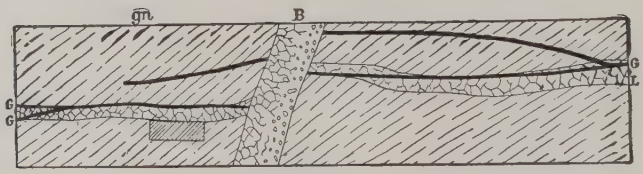


Fig. 169.—Ground plan of a drift in the Neu Unverhofft Glück at the Luxbach Annaberg. (H. Müller.)

gn, gneiss, micaceous; L, lamprophyre (fine-grained mica syenite); GG, lodes of the rich silver-cobalt ore formation; B, basalt, with fragments of gneiss and lamprophyre on one side.

various directions at 15-20°. Where the silver-cobalt veins cross these Schwebenden, they often show an extensive enrichment, as appears by the mine section, Fig. 170. According to H. Müller, at least half the entire output of silver and cobalt is derived from ore bunches found at these crossings, especially in the Bäuerin, Heilig Kreuz, Zehntausend Ritter, Himmlisch Heer, Galiläische Wirthschaft, König David and Markus Röhling mines. Besides these, there are others at the intersections of various mineral veins, and the junctions of various stringers are marked by the occurrence of rich ores.

The Annaberg veins are said to have been first opened for copper mining in the first half of the 15th century at the town of Geyersdorf, near the Pöhlberg. On October 27, 1492, a prospector discovered rich silver veins at the Schreckenberg, near Frohnau. By 1496 the "Neue Stadt am Schreckenberge" was formed by the great influx of foreigners. In 1497 the town received the name of Sanct Annaberg. In 1495 silver mines were

opened in the beech forest of the Schottenberg, which led in 1501 to the foundation of Sanct Katharinenberg in Buchholz, subsequently abbreviated to Bucholz. According to H. Müller, during the greatest period of prosperity of the Annaberg-Buchholz mining industry, from 1496-1600, a total of approximately 1,352,900 marks of silver and 48,460 centners of copper were obtained, having a total value of about 24,300,000 marks ($6,000,000) in present coinage. The industry declined from 1560 until towards the middle of the 17th century, when the utilization of the cobalt ores caused a gradual revival of mining activity. Cobalt mining was particularly active from 1701 to 1850, during which time 25,524 centners of cobalt ore were

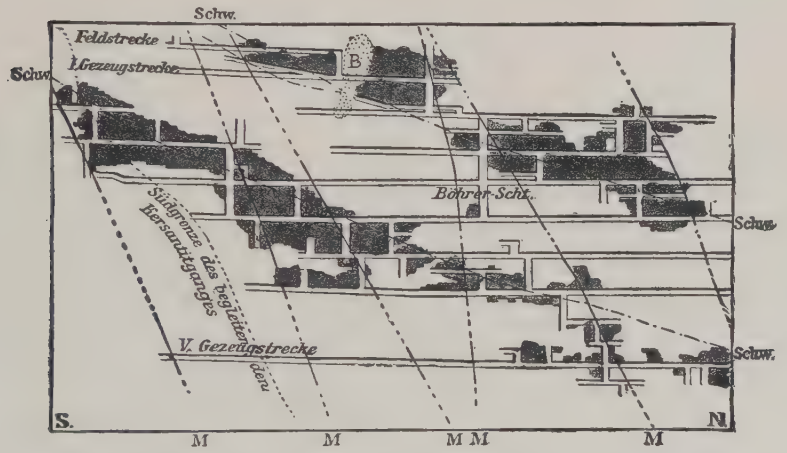


Fig. 170.—Longitudinal Section of the Heynitz Flache vein, Markus Röhling mine, Annaberg. (H. Müller.)

B, intrusive mass of basalt; Schw., "Schwebende"; M, various Morgengänge.

produced. The silver produced as a by-product during this time amounted to 26,945 kilograms. Since 1850 the mining industry has been at a low ebb.

Silver-cobalt veins as well as simple cobalt veins occur also at Schneeberg proper, as described farther on.

The same is true of the mining field of Johanngeorgenstadt. At the Fastenberg, the Eibenstock tourmaline granite is concealed by a cover of phyllite, which it has altered by contact metamorphism into spotted slate and andalusite-mica rock. These contact rocks are traversed by many dikes of fine-grained granite. Numerous mineral veins form a dense network in this rock, some belonging to the tin-cobalt and

some to the silver-cobalt formation, as well as pure cobaltic veins, all showing but little uniformity in strike. The veins are cut off by a vast network of iron ore stringers, the so-called Faule (rotten lode). The filling of the silver-cobalt veins of this locality is similar to that at Annaberg. They are often rich in uranium pitchblende.

Johanngeorgenstadt, the youngest mining town of the Erzgebirge, was founded as late as 1654 by the Protestants who were driven out of Bohemia, but mining began a few years earlier. It still continues, and produced in 1901 nine tons of bismuth and uranium ores.

The group of the silver-cobalt ore lodes also includes the deposits of Wittichen (Kinzig valley) and of Wolfach in the Black Forest, described by Vogelgesang[1] and F. Sandberger[2].

(ζ) Gold Veins.[3]

The gold veins are exceedingly varied in their composition, but may be grouped according to the prevailing gangue into: (1) Gold quartz veins; (2) Quartz-calcite veins, which contain other carbonates and rarely barite also; (3) Quartz-fluorite veins. The gold quartz veins contain a variety of gold-bearing sulphides and other minerals besides free gold. The predominance of a particular sulphide gives a special character to the particular example and thus various sub-divisions of the group may be distinguished. This differentiation of separate vein-types may be of practical interest, because of a corresponding difference in metallurgical treatment. Of course, these sub-classes are connected by transitions. The most important of them are the following:

Gold Quartz Veins (the Gold Quartz Formation).

(a) Pyritic gold-quartz veins in which pyrite prevails or at any rate predominates as compared to the other sulphides.

(b) Cupriferous-gold-quartz veins in which copper ore is prominent.

(c) Antimonial gold-quartz veins in which stibnite is abundant.

(d) Arsenical gold-quartz veins in which arsenopyrite is the predominant sulphide.

[1] Vogelgesang: 'Geogn.-bergm. Beschr. des Kinzigthaler Bergbaues.' Carlsruhe, 1865, p. 19.

[2] F. Sandberger: *Neues Jahrb.* f. Min., 1868, p. 385; also the volume for 1869, p. 290.

[3] A general discussion of the occurrence of gold in veins is given by Fuchs and De Launay: 'Traité,' II, 1893, pp. 890–893. ('Généralités sur les filons d'or.') E. Cumenge and F. Robellaz: 'L'or dans la nature.' Paris, 1898. Ed. Suess: 'Die Zukunft des Goldes.' 1877.

(e) Cobaltiferous-gold-quartz veins in which smaltite holds the gold.

Silver-Gold Veins.

The second main group, in which the gangue consists of quartz, together with earthy carbonates and sometimes barite, is also sharply defined by the fact that both gold and silver ores occur together, and gold-bearing and silver-bearing tellurides also occur very often.

Fluoritic Gold Quartz Veins.

The prevalence of fluorspar intermixed with the quartz and the presence of tellurides marks this group.

We will now give a detailed description of the different groups and cite examples of them.

16. Gold Quartz Veins.

These are simple or compound lodes, mostly of massive structure, and with the particles of ore irregularly distributed, or more rarely showing a banded structure, the individual thin or thick-sheeted layers being in such case divided by scales or films of ferric hydrate with free gold, or by talc, sericite, chlorite and other decomposition products. As shown by W. Lindgren, a *ribbon structure* is often present, having been produced by secondary movements and the formation of cracks, parallel to the strike, in the vein mass. This is proven by the pressed and crushed pyrite particles lying along the plates, and also by the forking of the joints between the quartz bands. In lodes that are rich in sulphides, however, a primary banding also occurs occasionally, in which case the ores are strongly concentrated along special planes parallel to the selvage.

The nature and habit of the quartz, the only essential gangue, varies greatly, and it is not possible to formulate any set of characteristics for the gold-bearing variety of this mineral, that may be applicable in all regions. In general it is a micro-crystalline, whitish, faintly translucent mass, appearing opaque to the naked eye, tinted grayish by finely divided sulphides in the deeper parts of the veins, and yellowish or rusty colored from the oxidation of those sulphides in the upper portions. The luster varies from glassy to greasy.

On examining a thin section of this with high powers of the microscope (see Fig. 171) the various individual grains show under polarized light a very irregular outline, which is but rarely formed even in part by crystal planes. Many specimens exhibit the marks of a strong secondary pressure, and the aggregations are often traversed by delicate, dark streaks represent-

ing slip or fracture planes, being minute fissures of displacement filled with extremely fine grains of crushed quartz, and ordinarily impregnated and colored with various ores or the products of their decomposition (see Fig. 171 c). Posepny[1], who described such minute shear planes in the quartz from the Tauern gold veins, explained these fissures as the result of a shrinkage of the mass in passing from an opal-like condition into a crystalline quartz, analogous to the process advocated by Fuchs and Breithaupt[2]

Fig. 171.—Gold quartz from Sheba mine.

a, large quartz crystals with enclosed liquids; b, small quartz grains formed by secondary crushing; c, brownish gliding zone, consisting of finely ground quartz ferric hydrate and gold particles; d, black spots are free gold.

on a large scale to explain the so-called Quarzbrockenfels of the Erzgebirge. It appears unlikely that this explanation will maintain itself.

Individual crystals of the gold-quartz are usually rich in liquid inclusions. As the bubbles disappear in most cases on heating the sections to 30° C., and reappear on subsequent cooling, it may be inferred that the liquid is carbonic acid. This, however, is not true in all cases. From a

[1] F. Posepny: 'Goldbergbaue der Hohen Tauern,' *Archiv f. Prak. Geol.*, I, Freiberg, 1880, p. 46.

[2] A. Breithaupt: 'Paragenesis,' 1849, p. 9.

chemical analysis by G. Steiger, Lindgren[1], for example, inferred that such liquid inclusions consisted of sulphates of calcium and alkalies, mixed with a small amount of chlorides. It is remarkable that the lines into which these inclusions are so often grouped sometimes pass through several adjoining quartz individuals without regard to the contours. W. M. Courtis[2] tried to establish definite relations between the microscopic structure of the gold quartz and the gold content of the lodes concerned, but was unable to find any rule of practical value.

Through the leaching out of the sulphides in the gossan, the gold quartz becomes porous. Such occurrences are sometimes erroneously designated as silicious sinter.

True sinter is probably deposited by the silicious water of some gold-bearing veins or lode-like deposits, though deposited only in the uppermost regions. The pure white, porous and even foam-like silicious sinters, suggesting pumice stone, seen in the gold deposit of Mount Morgan in Queensland and at some other Australian localities, are occurrences of this sort, which may without hesitation be compared with the deposits of some geysers, an assumption which is confirmed by the amount of water shown to exist in them.[3] Opal, too, has been described from gold quartz lodes, for example, in California. Its presence in veins need not be considered surprising, since opal, accompanied by gold-bearing pyrite and stibnite, has been observed in process of deposition by the spring waters of Steamboat Springs (see under 'Thermal theory') close below the surface of the earth, at the Monarch Geyser in the Yellowstone Park, and Boulder Hot Springs, Montana, and it is known that the thermal springs of Taupo in New Zealand produce a slightly auriferous silicious sinter.

Sometimes chalcedony is observed, for example in the gold ore veins of Donnybrook[4] in Western Australia. Here the chalcedony-quartz aggregates formed at first were afterward leached out in such way that a loose gold-bearing quartz dust remained.

For that matter, besides quartz, carbonates are not unknown in lodes of this group, as for example at Nevada City and in Grass Valley in California, and Idaho. However, they always play merely a subordinate part.

The native gold of quartz lodes is usually interspersed in the quartz grains in exceedingly fine scales, dust-like particles or small crystals, or

[1] W. Lindgren: 'Gold Quartz Veins of Nevada City,' etc., 17th *Ann. Rep.* U. S. Geol. Survey, 1896, p. 130.

[2] W. M. Courtis: 'Gold Quartz.' *Trans.* Am. Inst. Min. Eng., Vol. XVIII, 1890, p. 639.

[3] Weed, Walter Harvey: 'A Gold-bearing Hot Spring Deposit.' *Am. Journ. Sci.*, 3d Series, 1891, Vol. XLII, pp. 166–169

[4] F. Beyschlag and P. Krusch: 'Die Goldgange von Donnybrook in W. A.,' *Zeit. f. Prak. Geol.*, 1900, pp. 169-174.

lies wedged in between the surfaces of the quartz grains. More rarely is it found as dendrites, sheets, tangles of wires or crystalline lumps. The latter may in exceptional cases, as in that of a specimen from Monumental Mine, Sierra County, California, attain a weight of 43.08 kilograms. (See discussion of gold nuggets under the head of placer gravels, farther on.) Such nuggets are always jagged in outline and usually coated with crystals of gold. A special form is exhibited by the aggregations of gold derived from the decomposition of tellurides. They form dark yellow moss-like or spongy crusts, which, because of their color, are popularly termed "mustard gold."

At times the gold is so exceedingly finely divided as to suggest that it is contained as a silicate in the quartz of some lodes. This assumption is unnecessary, since the fineness of the flakes may far exceed our ordinary visual power. J. A. Edman,[1] using very strong magnifying powers, was able to detect, in quartz, particles of gold dust whose diameter was only from 1/40 to 1/480 of a millimeter.

All the gold of this type of veins contains silver. The degree of fineness differs greatly. In California, for example, in the case of gold dust it is 0.850 to 0.870, while in larger nuggets it is up to 0.950.

The sulphides, which often occur in great abundance in the lodes, and are rarely entirely absent, are developed either in finely interspersed crystals and granules, or in compact aggregates. The most widely distributed sulphide is iron pyrite, which is sometimes, but rarely, replaced by pyrrhotite. Associated with the pyrite there is also copper pyrite, galena, zinc-blende, arsenopyrite, stibnite, as well as molybdenite, all of which are apt to contain gold and silver.

The lodes often enclose fragments of country rock, which in such cases are usually more or less strongly impregnated with gold, auriferous pyrite and other ore minerals, as is also the case with a zone of the adjoining country rock along the vein-walls.

Gold quartz veins occur in all kinds of rocks, but are most frequent in crystalline schists. They most often occur in regions where the older schistose rocks are broken through by granitic, dioritic and diabasic rocks and are genetically connected with such intrusions as will be shown in describing the various examples.

The genetic connection of many gold quartz lodes with granitic intrusive masses has been brought into prominence by late researches. They cluster about the borders of the granite areas in Montana, and elsewhere, even the ancient veins of the Appalachian gold belt showing this association. It has been shown that some of these lodes show a close relationship to pegmatite

[1] Cited by E. Cumenge, *op. cit.*, p. 40.

veins. J. E. Spurr[1] has shown that gold quartz veins contain a great number of such accessory minerals as are also characteristic of pegmatite veins, although the amount is trifling compared to the gangue proper, the quartz. Thus among the 62 mineral species enumerated by G. F. Becker[2] from the gold veins of the southern Appalachians, there were, among others, tourmaline, cassiterite, apatite, orthoclase, albite, garnet and scheelite. In the Fortymile and Birch Creek districts of the Yukon, Spurr observed what he considered to be transitions from gold quartz lodes to aplites, that is to say, finely crystalline granites, poor in mica (alaskite), which often passed into pegmatites. These transitions take place very gradually by an increasing abundance of feldspar. This phenomenon only became intelligible after the work of W. O. Crosby, M. L. Fuller, W. C. Brögger and others had afforded us a better understanding of the probable conditions under which pegmatites are segregated. These conditions must have been intermediate between those under which an acid eruptive rock congealed, and those under which an ordinary quartz vein was segregated. As the water and various gaseous compounds become more and more concentrated in a residual "mother liquor" during the crystallization of the magmas, these residual solutions, charged with silicic acid, penetrate from the contact into fissures and deposit vein quartz, together with metallic and non-metallic compounds, which were previously uniformly distributed in the molten magma, but gradually retreated into this residual water.

The reader should compare these deductions with what was previously said (page 14) on the processes of magmatic differentiation.

Independent of the above mentioned American authors, E. Hussak expressed similar views in regard to the deposits at Passagem (see later).

From this point of view, the genesis of such gold quartz veins is analogous in nature, though of very different material, to that of tin veins, whose genesis is discussed farther on. The statements just made also apply particularly to the cuprous gold quartz veins characterized by the presence of tourmaline.

I. *Pyritic Gold Quartz Veins.*[3]

A typical development of this class is found in the famous "gold belt" of

[1] J. E. Spurr: 'Geology of the Yukon Gold District, Alaska.' 18th *Ann. Rep.*, U. S. Geol. Surv., III, 1896–97, p. 298, *et seq.*

[2] G. F. Becker: 'Goldfields of the Southern Appalachians.' 16th *Ann. Rep.*, p. 274.

[3] M. Laur: 'Du gisement et de l'exploitation de l'or en Californie.' *Ann. d Mines*, 1863, Ser. VII, Vol. III. J. D. Whitney: 'Geol. Surv. of California,' 1865, Vol. I. H. W. Turner: 'Notes on the Gold Ores of California.' *Amer. Journ. of Sc.* 1894, pp. 467–473. 'Geolog. Atlas of the United States,' Californian folios, 1894, etc., W. Lindgren: 'The Gold-Silver-Veins of Ophir, California,' 14th *Ann. Rept.* U. S. Geol. Surv., 1894, pp. 249–284. *Ibid.*: 'Characteristic features of California Gold-

California. This very extensive mineralized area lies on the west flank of the Sierra Nevada, sloping gently toward the great longitudinal valleys of the Sacramento and the San Joaquin rivers.

This great mountain range is essentially composed of slates of Carboniferous (Calaveras formation) and Jura-Triassic (Mariposa formation) age, which are everywhere broken through by granite rocks and altered by contact-metamorphism. Black slates with limestone intercalations and diabasic intruded masses, as well as sandstones, prevail in both the two formations. The beds appear overturned, probably in consequence of an overfold in an easterly direction, and a steep easterly dip prevails. The beds strike north, or toward the axis of the range, which runs northnorthwest. After some older folding and faulting, the principal uplift of the range began in late Tertiary time.

The gold veins are in the main parallel with the older folds, that is, parallel to the axis of the range. The main so-called 'mother lode' is a zone of veins 70 miles long, 6½ miles wide, extending from Mariposa County (Mount Ophir) to beyond Placerville, and often following the contact zones of intrusive plutonic masses. It is, in fact, a collection of parallel quartz veins, often interrupted, which either coincide in strike with the black clay slates of the Mariposa formation, or cross them at a very acute angle. The dip is usually east at 50 to 70°, and follows in the main the dip of the slates. The thickness of the larger veins is often 10 m. (32.8 ft.) or more, but occasionally decreases to 1 m. (3.3 ft.) North of the Lawrence mine the mother lode breaks up into stringers, and finally resolves itself into a tangled network of small, often highly auriferous quartz stringers, associated with a definite slate zone (seam diggings). Other important veins occur independently of the mother lode, in the contact zone between the Calaveras slates and the granite at Grizzly Flat, southeast of Placerville, others to the north at Grass Valley and Nevada City. Some of the lodes follow for some distance the contact between the slates and intercalations of altered diabase rocks. The veins are sometimes displaced by cross faults, as observed by Laur.

Outside of the real gold belt of the Sierra Nevada, California contains various other gold veins of less importance, for example in the Coast Range at San Diego.

The workable ore occurs in pay shoots in true fissure veins, best developed in schists, and absent in serpentine. Very large outcrops of white quartz are low grade, lenticular, and pinch out. (Ransome.)

quartz veins,' 1895, *Bull.* of the Geol. Soc. of Am., Vol. VI, p. 221. *Ibid.*: 'The Gold-Quartz-Veins of Nevada City and Grass Valley Distr., Calif.' 17th *Ann. Rept.* U. S. Geol. Surv., 1896, pp. 13-262. B. Knochenhauer: 'Der Goldbergbau Californiens' Leipzig, 1897. F. L. Ransome: Gold Belt,' folio, U. S. Geol. Surv.

In all these lodes, the only gangue is quartz, which in the richer occurrences tends to separate into thin layers (ribboned quartz), while in the poorer ones it is more massive. In this quartz the gold is usually interspersed as very fine, hardly perceptible particles, more rarely in larger aggregations. The fineness of this gold is as a rule 850-870. The gold is always accompanied by gold-bearing pyrite, occasionally also by zinc-blende, galena, copper pyrite, arsenopyrite and tellurides, rarely by pyrrhotite, molybdenite, tetrahedrite, cinnabar and antimonial-lead ores. The concentrates contain 120-140 gm. (3½ to 4 oz.) gold to the ton, rarely more. The average amount of gold in the total amount of ore extracted is assumed by B. Knochenhauer to be 15-20 gm. (0.4 to 0.6 oz.) per ton. In the gossan, which extends to a depth of 40 m. (131 ft.), rarely to 60 m. (196 ft.), much higher values were found, 125-160 g. (3.7 to 4.7 oz.) per ton being not infrequent.

Though the amount of gold gradually decreased below the gossan, yet in the undecomposed zone itself no decided impoverishment or even barrenness has yet been observed in the Californian lodes. The shafts of Kennedy mine near Jackson City encountered workable gold ore even at 600 m. (1,968 ft.) to 655 m. (2,150 ft.) The distribution of the gold in the lodes, it is true, is not uniform. Ore shoots occur in overlapping lenses and ordinarily replace each other in such fashion that one wedges out downward, while a new one wedges in somewhat to the side.

The origin of these lodes is thought by Lindgren, one of the best posted authorities, to be independent of the country rock, and hence the veins cannot have been formed by lateral secretion as that theory is understood in its narrower acceptation, but rather by rising thermal waters, charged with silica, various carbonates and carbonic acid. This hypothesis is further strengthened by a study of the alteration of the vein walls and the included material. This rock is altered with the formation of carbonates and partial sericitization.

The auriferous wealth of California was discovered in 1848. The production continues to be considerable; in 1903 the total production was $16,363,000, of which $1,475,749 was produced by dredges working in the river bottoms, while $872,812 was the result of hydraulic mining and $905,679 of drift mining.

During the last 50 years, California produced gold to the value of $1,251,696,817, an annual average of $25,031,936. In 1898 the gold production was 22,418 kilograms, $15,906,478; for 1903 it is in round numbers $16,363,000, or including the $498,412 commercial value of silver alloyed with the gold, it is $16,861,412.

Gold veins of this type are also found in various other parts of the United

States, as in Idaho[1], Oregon, southern Alaska[2], the Yukon[3] gold district, and in part also in the southern Appalachians[4]. A special description of these areas, treated in a masterly way in the works cited below, would exceed the limits of space of the present work.

In South America an important mining district containing this kind of gold vein occurs at Callao, on the right bank of the Yuruari, south of the Orinoco delta, in the so-called Caratal district of Venezuela. The lodes of this region are remarkable in that the pyrite is subordinate in amount to the free gold, which is probably due to a specially deep secondary decomposition of the pyrites. The region exported from 1866 to 1886 the grand total of 55,862 kilograms of gold[5].

Pyritous gold quartz lodes are also worked in Dutch Guiana (Surinam) and in British Guiana.

A grand development of the pyritous gold quartz formation is witnessed in Australasia[6], both on the continent and on the islands of New Zealand and Tasmania. Out of a great number of examples, we can only select a few.

A large and rapidly rising gold production has recently drawn attention to the gold fields of West Australia, whose veins are mostly of the class under discussion.

The gold field of that region, which covers an area greater than Germany, occurs in the arid tableland of Western Australia, and owing to its lack of water and wood, presents great difficulties to mining enterprises. The country consists of upturned clay slates, quartzites, mica schists, phyllites, talcose schists and chloritic schists, with many diorite and diabase dikes, which have often been transformed by pressure into schistose amphibolites. In the Coolgardie district, east-northeast of the port of Perth, at Kalgoorlie and elsewhere, these rocks are traversed by many zones of decomposition, mostly striking north-northwest or north-northeast and penetrated by numerous auriferous quartz stringers. Simple gold quartz lodes, often developed as bedded or lenticular veins, sometimes traverse the country rock. While the stringer zones do not show at all on the surface, the simple quartz lodes, called 'reefs,' often form long and high quartz crests, a prominent

[1] Lindgren: 'Mining Districts of Idaho Basin,' 18th *Ann. Rep.* U. S. Geol. Survey, 1898. 'Blue Mts. of Oregon,' 22d *Ann. Rep.*, 1902.

[2] G. F. Becker: 'Recon. Gold Fields Southern Alaska,' 18th *Ann. Rep.* U. S. Geol. Survey, 1898, III, pp. 1–86.

[3] J. E. Spurr: 'Geol. of Yukon Gold Dist., Alaska,' 18th *Ann. Rep.* U. S. Geol. Survey, 1898, III, pp. 87–392.

[4] G. F. Becker: 'Gold Fields of Southern Appalachians,' 16th *Ann. Rep.* U. S. Geol. Survey, 1896, III.

[5] C. Le Neve Foster: 'On the Caratal Goldfield.' *Quart. Journ.* Geol. Soc., XXV, 1869, p. 236. Fuchs and De Launay: 'Traité,' II, pp. 896–902.

[6] K. Schmeisser: 'Die Goldfelder Australiens.' Berlin, 1897. Wolff: 'Das Australische Gold, seine Lagerstätten und Associationen.' *Zeitschr.* d. d. G. G., 1877.

feature in the landscape. The gold is free in some veins, as in the Great Boulder main reef at Kalgoorlie, and also occurs in calaverite and other tellurides of various kinds, and is everywhere associated with pyrite. Besides this, some arsenopyrite, galena, copper pyrite and some rarer ores are mentioned. The telluride lodes, according to Pittman, accompany eruptive dikes of porphyries now altered to schists. They form perhaps a special type and should not be included in the gold-quartz veins. The amount of gold in the quartz lodes averages, according to K. Schmeisser[1], 30-60 gm. per ton ($20-$40), and in the quartz stringers of the compound lodes and alteration zones 30-120 gm.; in the rest of the filling of these shear zones it reaches at most 30 gm. per ton. In exceptional cases, some mines for a while recorded a gold content of the ore treated in their stamp batteries of 90-470 grams per ton. The gold content decreases almost everywhere from the zone of oxidation downward. According to H. C. Hoover, at a depth of but 30 m. (98 ft.) it has declined to one-half, or even to one-fourth of the amount found at the top.

The remarkable residual placer gold deposits of this region, called cements, are discussed under gold-bearing gravels.

The gold production of West Australia in 1898 was 29,218 kilograms of fine gold. In 1902 it was 1,819,308 oz. or $82,454,344.

Most of the gold veins of Victoria belong to the pyritic gold-quartz type, with transitions to the arsenical type, the most important districts being Ballarat, Beechworth, Bendigo (Sandhurst), Maryborough, Castlemaine, Ararat and Gippsland. The veins occur mostly in Silurian slates and in many cases are closely related to dioritic eruptive masses. We have already described the remarkable saddle lodes of Bendigo in the Sandhurst district. This district also contains the largest deep mines of Australia. One shaft on these gold quartz lodes has, according to Lindgren, reached, in 1904, a depth of 4,000 ft.[2] Mention has already been made of the 'ladder' lodes of Waverley.

In New South Wales[3], veins of this class occur in the Wyalong goldfield, and in Queensland at Charters Towers[4]. In the latter area the pyrite is in part replaced by auriferous pyrrhotite. This same colony also contains the

[1] K. Schmeisser: 'Die Goldfelder Australiens.' Berlin, 1897. p. 43. A. Gmehling: 'Beitrag zur Kenntniss der Westaustralischen Goldfelder.' *Oesterr. Z. f. B. u. H.*, 1898, p. 161, and 'Ueber die Golderzlagerstätten von Coolgardie.' Ebenda, 1897, p. 425. Sloet van Oldruitenborgh: 'Technical observations upon the Coolgardie Goldfields.' *Mining Journal*, 1897, p. 819. P. Krusch: 'Zeit f. Prak. Geol.,' 1901, pp. 211-217.

[2] 'Gold Veins of Victoria,' *The Engineering and Mining Journal*, March 9, 1905.

[3] E. F. Pittman: 'On the Geol. Structure of the Wyalong Goldfields.' *Records* Geol. Survey, N. S. W., 1894, p. 107.

[4] R. L. Jack: *Report* on the Geology and Mineral Resources of the District between Charters Towers Goldfields and the Coast, 1879.

Crocodile goldfield, 42 km. (25.2 miles) southwest of Rockhampton, with the remarkable deposit of Mount Morgan, which deserves a few remarks.

Mount Morgan, "the greatest gold deposit of the earth"[1], rises 152 m. (498 ft.) above Linda (Mundic) Creek and 1,225 ft. above sea level. It is an obtusely conical hill, by far the greater part of which consisted of workable gold ore. Its summit has long been removed by open-cuts, and its deeper parts have been explored in all directions by drifts and stopes extending even below the bottom of the valley. Down to a depth of 90 m. (295 ft.) the ore is very uniform, consisting of bluish-gray quartz, silicious red hematite, colored light red to bluish black, brown hematite and manganese iron ore, together with white, vesicular, often foam-like, silicious sinter, kaolin and ocherous earth. Below 90 m. (295 ft.) this gossan changes into a gold-bearing and pyrite-bearing quartzite. The average gold content decreased constantly downward, toward the end very slowly, from about 115 grams to 40 grams per ton. The production of this single mine in 1896 was some 95,000 tons of ore with 4,560 kilograms of gold. In the year ending May, 1902, 213,907 tons of ore were treated, yielding 147,628 oz. of gold.

The form of the deposit is stock-like, tapering downward, and it is traversed by several dikes of dolerite, rhyolite and felsite which, according to T. A. Rickard, are genetically associated with the impregnation of the entire rock mass with gold-bearing quartz. On the other hand, the occurrence of silicious sinter, which seemed to indicate a deposition of dissolved silicic acid near or on the earth's surface, induced R. L. Jack to interpret Mount Morgan as a geyser formation[2]. It seems premature to pronounce in favor of either view, especially as the argument for the former does not seem to include a definite statement as to the petrographic character formerly possessed by the main rock mass of the mountain, which is now completely silicified and mineralized.

This class also includes most of the veins of the African goldfields. We will mention but one example, the famous Sheba mines[3] near Eureka City in the Transvaal, whose ores created universal astonishment by their remarkable richness, up to 250 grams per ton, when the work was as yet confined to the gossan. These mines lie in the DeKaap goldfield between Delagoa bay and the capital of the former Transvaal republic.

[1] R. L. Jack: 'Reports of the Queensland Geolog. Survey,' 1884, and 'Mt. Morgan Gold Deposits,' 1892. T. A. Rickard: 'The Mt. Morgan Mine.' *Trans.* Am. Inst Min. Eng., XX, 1891, p. 133. K. Schmeisser: *op. cit.*, pp. 81–84.

[2] W. H. Weed: 'A Gold-bearing Hot Spring Deposit.' *Amer. Jour. Sci.*, 3d series, Vol. XLII, pp. 166–169.

[3] P. R. Krause: 'Kurze Schilderung der Grubenbezirke von Pilgrim's Rest.' *Zeit. f. Prak. Geol.*, 1897, p. 22.

Mention may also be made of the gold deposits in Matabeleland and Mashonaland, the ancient Semitic mining settlements of Zimbabwe[1], and, lastly, of the lodes exploited by the ancient Egyptians in the desert that lies between the Nile and the Red Sea[2].

Asia, in the Ural and the Amur country, presents numerous deposits of this kind. Among the Ural deposits belonging to this class the veins of the areas east of the mountains proper, at Chelcabinsk, where the great Siberian railway begins, are worthy of mention. The rock of this locality, according to A. Karpinsky[3], is a highly dynamo-metamorphosed granite, in part a hornblende granite. This is traversed by numerous gold-bearing veins, some striking northeast, some northwest. The vein filling consists of completely decomposed country rock and of quartz. The latter usually forms solid vein stringers 0.2-0.7 m. (0.6-0.22 ft.) thick, exceptionally 2 m. (6.6 ft.), or may also pervade the decayed granite in a network of veins. In the upper part of the vein the quartz contains free gold, but at a depth of 30-40 m. auriferous pyrite and arsenopyrite make their appearance. The gold content varies as a rule between 2.0 and 10.4 grams per ton. However, enrichments with 30 grams per ton and above have been encountered. Some of the veins, like those of California, are built up very regularly out of quartz layers 2-5 cm. thick. These veins are especially notable because of their gold-bearing pyrites and the presence of ocher enclosing free gold. Such a lode, when its dip is very low, as in the Ivanovsky vein, which dips north-northwest at 15°, is at first often taken for a bed.

Among the Siberian gold veins of this kind, we will merely mention that of Onon[4], west-southwest of Nerchinsk in Transbaikalia. The lodes there are associated with aplites traversing Paleozoic schists.

Of European gold quartz veins of this type, the Hohe Tauern veins of the eastern Alps are best known. The mines are still worked in Goldberg of Rauris and at the Rathhausberg, near Gastein[5]. Gneisses and other crystalline schists of the central Alps are traversed by narrow quartz veins, usually so thin as to be called 'leaves.' These contain extremely fine

[1] R. Rugg: 'Matabeleland, its Goldfields,' etc. London, 1891. *Idem.*: 'New map of Matabeleland, Mashona and Tati Goldfields,' London, 1891. A. G. Sawyer: 'The Goldfields of Mashonaland,' with 21 maps and plates. London, 1894. Th. Bent: 'The Ruined Cities of Masjonaland,' London, 1896. C. Peters: 'Im Goldlande des Alterthums.' Munich, 1902.

[2] Ch. A. Alford: Reference in *Zeit f. Prak. Geol.*, 1902, p. 9.

[3] 'Guide des excursions du VII Congres. Geolog. International,' 1897, V, p. 30.

[4] E. D. Levat: 'L'Or en Siberie Orientale.' I, p. 64.

[5] B. v. Cotta: 'Erzlagerstätten.' II, pp. 318–324. F. Posepny: 'Goldbergbau der Hohen Tauern.' *Archiv f. Prak. Geol.*, I, 1880, p. 1 *et seq.* R. Canaval: 'Das Bergbau-Terrain in den Hohen Tauern.' Klagenfurt, 1896. With bibliography. P. Krusch: 'Die Goldlagerstätten in den Hohen Tauern.' *Zeit. f. Prak. Geol.*, 1897, p. 77 *et seq.*

particles of free gold, with pyrite and a number of other sulphide ores, such as copper pyrite, arsenopyrite, galena, zinc-blende and stibnite, and very rarely molybdenite and various rich silver ores. Because of this highly varied mixture of ores, in which, however, pyrite greatly predominates, the veins are not so truly typical of the class as the Californian or Australian gold quartz lodes. They form a transition from the pyritic-gold-quartz veins to the pyritous lead formation. A feature of special importance in these Tauern 'leaves' is the strong impregnation of the wall-rock with ore, which in some cases has led to the development of banded masses resembling beds, as at the Heinzenberg, near Zell, in Tyrol. The production of the Rathhausberg in 1898 was only 76.7 tons of gold-bearing concentrates.

A more typical development of the pyritic gold-quartz vein is seen in the Piedmont Alps, as for example at Brusson[1].

In Bohemia, mention must be made of Eule-Jilova[2], between the valleys of the Sazava and the Libre. Besides pyrite and free gold, the ores also carry arsenopyrite. The mining industry of Eule is extremely ancient, dating back to the end of the 8th century. This place may have been the greatest producer of the former golden wealth of Bohemia. In 1898 the work at Jilova had almost entirely stopped and only 38 tons of gold ore were produced. On the contrary, the Borkowitz mines in the Kuttenberg district produced during the same year 2,288.4 tons of gold ore. Work has also been recently resumed on pyritous gold ore lodes at Mount Roudny, east of Wotitz.

II. *Cupriferous Gold-Quartz Veins.*

In this type, the quartz gangue contains not only free gold and auriferous pyrite, but also a good deal of copper pyrite and other copper ores. Tourmaline is very often a characteristic accompaniment. The lodes are generally connected with acid eruptive rocks, especially granites.

The best known example of this type of vein is found in the vicinity of Berezovsk (Berjosowsk)[3], near Ekaterinburg, on the east slope of the Ural mountains.

Berezovsk lies in a low-rolling region, covered with pine and willow, and underlain by a muscovite granite schist and mica schists, strongly affected by dynamo-metamorphism and deeply decomposed. These talcose, chlorite

[1] C. Schmidt: 'Geol. Gutachten,' Berne, 1900.

[2] F. Posepny: 'Goldvorkommen in Böhmen,' *Archiv f. Prak. Geol.*, II, 1895, p. 79.

[3] B. von Cotta: 'Erzlagerstätten,' II, pp. 554-556. F. Posepny: 'Golddistricte von Berezov und Mias im Ural,' *Archiv. f. Prak. Geol.*, II, pp. 499-598. A. Karpinsky: in 'Guide des excursions du VII. Congrès Géolog. Internat.,' 1897, V, p. 42. With bibliography.

and clay schists, all of which in the decomposed, reddish-colored condition, are called 'krassik,' are traversed by numerous vertical dikes, 2-40 m. (6.6 ft. to 131 ft.) thick, running north and south. The dike rock is a micro-granite called beresite, and this rock is also decomposed down to great depth. These dikes have been exposed by deep open-cuts and extensive galleries and shafts. At right angles to the strike of these beresites, extending from wall to wall, and sometimes for short distances past the dike wall, there are numerous veinlets or stringers of gold-bearing quartz, which are seldom over a few cm. (3 inches) thick, but in exceptional cases as much as 1 m. (See Fig. 121.)

Besides free gold, these quartz veins carry a variety of sulphide ores and the products of their decomposition; according to B. von Cotta these sulphides consist of pyrite, some aikinite ($PbCuBiS_3$), gray copper, copper pyrite and compact galena, as well as red lead ore, melanochroite, vauquelinite, pyromorphite, vanadinite, cerussite, anglesite, limonite, and bismuth ocher. Very frequently the quartz also contains long needles of a gray-green tourmaline, running at right angles to the walls, as well as small crystals or radiating balls of pyrophyllite, and sometimes magnesite. A very remarkable phenomenon is the presence of pseudomorphs of a chrome-bearing tourmaline after pyrite, which are occasionally found in these gold quartz stringers, as illustrated by specimens in the collection of the Moscow University.

Besides free gold, these veins also contain gold in the pyrite. According to A. Karpinsky, it varies between 2.5 and 30, locally even 250 g. per ton. The average may be assumed at about 13 g. per ton.

The micro-granite dikes (aplite veins) carrying the gold quartz stringers may be genetically connected with the granite massive of Lake Shartash, which is not far away. The chips of this perfectly fresh rock knocked off in quarrying it for use in stairways and steps, door jambs, etc., are credibly stated to contain as much as 1 gm. (66 cents) of gold per ton. If thus the intrusive stock proper is auriferous, it need not be wondered at that the subsequent extrusions from the same magma hearth in the form of aplites also brought with them a gold content, which was concentrated in the quartz stringers. These quartz stringers must, it would seem, be accepted as having the same origin as pegmatite. See other statements on this subject on page 297.

The gold veins of Berezovsk were discovered in 1745, and the mines are still being worked.

The cupriferous-gold-quartz class of veins also includes most of the gold veins of Scandinavia. On Bömmel Island, on the west coast of Norway, between Bergen and Stavanger, veins of this class have been described by

Th. Scheerer and afterward by H. Reusch,[1] and have been mined since 1884 by an English company. The rocks consist mainly of a saussurite gabbro, broken through by quartz porphyry and dikes of a diorite altered by dynamo-metamorphism. The gold quartz veins occur in these rocks, especially in the quartz porphyry. Their thickness may amount to as much as 1 m., strike northeast, dip 25-45° southwest. The vein filling consists of quartz, some calcite and chlorite, with free gold, copper pyrite, pyrite, galena and at times tetradymite (bismuth telluride) and very rarely native silver. The gold content of the ore, according to H. Louis, varies between 7 and 28 g. per ton.

The gold-bearing tourmaliniferous copper veins in the Thelemark area of southern Norway have already been mentioned. The gold veins of Eidsvold, too, 75 km. (45 miles) north of Christiania, should also be mentioned here.

In Sweden the cupriferous gold quartz veins are represented by the lodes of Adelfors in Småland, as well as by gold quartz stringers in the pyrite stock of Falun (*q. v.*).

Very typical examples of the cupriferous gold quartz veins have been reported by W. Möricke[2] in Chile. They represent an extreme variation of our group of the tourmaline-bearing copper formation. Besides quartz with tourmaline, they contain pyrite, free gold, copper pyrite and other copper ores. They are also apt to be associated with granites and other acid eruptive rocks. As examples may be mentioned the veins of Guanaco, Andacollo and Los Sauces in Chile.

In Australia also gold-quartz veins rich in copper ores seem to be rather common, especially in New South Wales, judging by the material in our collection. Whether they carry tourmaline or in other ways form a well characterized group, has not yet been ascertained.

On the Philippine Islands, according to oral statements by F. V. Voit, this class is represented by the veins of Mambulao and Paracale. A Transvaal example on the Malmani river is a vein in dolomite in the Marico District[3].

A unique type of gold vein occurs at Rossland, B. C., characterized by Lindgren[4] as biotitic gold copper veins. They are well marked fissure veins, contained in granular intrusive rocks, ranging from diorites to monzonites and even syenites. The ore minerals are pyrrhotite, chalcopyrite and a little arsenopyrite, all holding gold, but usually not free, or amenable to amal-

[1] H. Reusch: 'Bömmelöen og Karmöen, Cristiania,' 1888, p. 392. Phillips-Louis: Ore Deposits,' 1896, p. 519.

[2] W Möricke: 'Die Gold-, Silber- und Kupfererzlagerstätten in Chile,' 1897.

[3] G. A. F. Molengraaff: 'Géol. de la Rep. Sud Africaine,' 1901, p. 40.

[4] W. Lindgren: 'Metasomatic Processes,' *Trans.* Am. Inst. Min. Eng., 1900, p. 69.

gamation. The chief gangue mineral is biotite, with a little quartz, calcite, muscovite, amphibole, chlorite, tourmaline and garnet. The veins are replacement deposits along fissures, the hornblende of the rock altering to biotite, and the feldspar replaced by pyrrhotite and chalcopyrite. The process indicates dynamic metamorphism rather than ordinary vein-forming processes.

III. *Antimonial Gold-Quartz Veins.*

In place of pyrite this class contains stibnite as a characteristic companion of the free gold, the antimony glance itself being gold-bearing. As subordinate minerals of these veins pyrite still continues to appear with arsenopyrite, rarely galena, blende and copper pyrite, and, together with quartz, there may be a slight amount of carbon spars.

Good examples of the class are seen in the mineral district of Krásnáhora (or Schönberg) and Milesov (or Mileschau) in central Bohemia, southwest of Prague, described by F. Posepny[1]. An intrusive stock of granite intercalated between schists, is traversed by a few porphyry dikes and numerous ones of lamprophyre. Most of the veins accompany these dikes. Besides quartz as the principal gangue, they carry some calcite, and as ore minerals, stibnite with a gold content of 100-133 g. ($66.00 to $87.88) per ton, arsenopyrite and pyrite, together with about 300-400 g. ($198-$264) per ton in native gold in scales and botryoidal aggregations in the quartz; also antimony, ochre and pyrostibite. The stibnite often constitutes the larger part of the filling. Masses with a thickness of as much as 1 m. (3.28 ft.) are said to have been found.

At Mileschau a thriving gold mining industry was carried on as early as the fourteenth century. Of late years the mines have been worked for stibnite. Incidentally, however, in the production of 661.5 tons of antimony ore in 1898, 254.3 tons of gold quartz and 180.4 tons of gold-bearing pyritic concentrates were produced at Schönberg and Proutkowitz.

Another typical example of this class occurs, according to B. von Cotta[2], at Magurka, in Hungary, on the north slope of a granite range, 1,200-1,800 m. high, separating the Comitat of Sohl from Liptau. The granite is there traversed by quartz veins varying from a few cm. (or inches) to 4 m. (13 ft.) thick. The veins contain stibnite and free gold, together with balls of granite. The accessory minerals are galena, zinc-blende, pyrite, copper pyrite, brownspar and calcspar. Ordinarily the quartz occurs along the walls of the vein, while the stibnite is found in the middle of the vein.

This class also includes the veins of the well-known district of Brand-

[1] R. Helmhacker: 'Der Antimonbergbau Milesó bei Krásná Hora,' 1874. F. Posepny: 'Goldvorkommen, Böhmens,' *Archiv. f. Prak. Geol.*, 1895, p. 165.

[2] B. von Cotta: *Berg u. Hutten. Zeit.*, 1861, p. 123.

holz, near Goldkronach[1], in the Fichtelgebirge. At this place Cambrian sericite schists are cut by quartz veins, containing subordinate quantities of brownspar, more rarely calcspar, and occasionally barite, and carrying stibnite, gold- and silver-bearing pyrite and arsenopyrite and free gold, besides very small amounts of striated galena, brown blende, native antimony, antimony ocher, stiblite, heteromorphite and bournonite. The quartz is often thoroughly impregnated with minutely disseminated ores. The veins often wedge out and are for some distance replaced by a simple fissure, alongside of which the adjoining rock is silicified and impregnated with arsenopyrite and iron pyrite. Mining, which dates back to the fourteenth century, was resumed after the transfer of the principality of Bayreuth to Prussia, about 1800, in part under the management of A. von Humboldt, but was again abandoned in 1861.

Antimonial gold quartz veins occasionally occur in gold ore districts outside of Europe; for example, at several points in Australia, in the Selati goldfield and in the Murchison range in the Transvaal.

In the last-named mountains, hornblende schist and quartzite schist are traversed by a series, almost 35 miles long, of veins which generally follow the strike of the schists in the form of beds, and contain quartz with auriferous antimony glance, in part also with gold-bearing pyrite and copper pyrite. The Invicta, Free State and Gravelotte mines are operated on such veins.

IV. *The Arsenical Gold-Quartz Veins.*

In this class free gold is accompanied by arsenopyrite as the most prominent of the ore minerals in a gangue of quartz.

Such veins have been worked since 1881 at Santa Cruz, in the state of Santa Barbara, Honduras[2]. The principal veins, 2 m. thick on an average, consist of quartz, gold-bearing arsenical pyrite and mere traces of galena. The ore contained 25-30 gm. per ton.

Occurrences of similar kind are scattered all over North America, being mostly connected with the pyritous gold quartz veins by transitions. The veins in the Huronian schists at Marmora, Ontario[3], Canada, are typical examples.

The peculiar arsenical gold ore deposits, regarded by many as beds, at Passagem in Brazil, are peculiar, as will be seen by a brief description, taken from E. Hussak.

[1] C. W. Gümbel: 'Fichtelgebirge,' 1879, pp. 386-393. F. v. Sandberger: 'Ueber die Erzlagerstätte von Goldkronach bei Berneck,' *Sitzber.* d. math-.phys. Cl. d. k. bayer. Ak. d. W., 1894, Vol. XXIV, part II.

[2] Fuchs and De Launay: 'Traité,' II, p. 942.

[3] R. P. Rothwell: 'The Gold Bearing Mispickel veins of Marmora, Ontario, Canada,' *Trans.* of the Amer. Inst. of Min. Eng., 1881.

Passagem[1] lies in the province of Minas Geraes, 7 km. (4.2 miles) east of Ouro Preto. Next to Morro Velho it is to-day the most productive gold mine of Brazil, and has been worked since the end of the last century.

According to Hussak, the most important deposit of the locality is a bedded vein of quartz, carrying tourmaline and auriferous arsenopyrite, with subordinate amounts of pyrite and pyrrhotite in patches. It dips southeast at an angle of but 18-20°, and is entirely conformable with the enclosing quartzite schist. The latter is part of a series of rocks made of hematite mica schist and of mica schists and itabirite[2].

The matrix is here and there replaced by lenticular masses of sericite-quartzite schists. Near the underlying mica schist, which contains stauro-

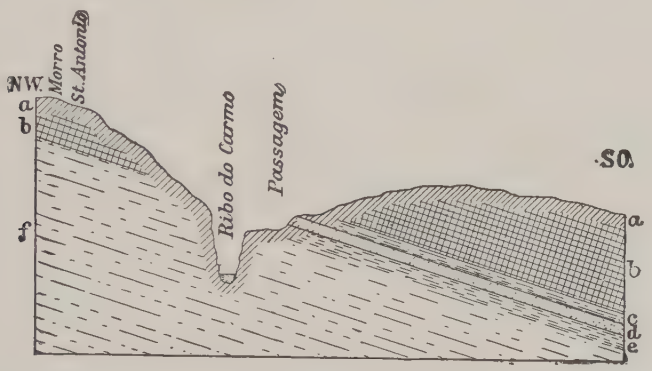


Fig. 172. Cross-section through the quartz bed of Passagem. (M. P. Ferrand.)
a, canga (weathered cover); b, itabirite; c, crypto-crystalline schist; d, quartz vein and quartzites; e, contact quartzites; f, mica schist.

lite and cyanite, a selvage zone or streak of black graphitic schist occurs, and this material is also occasionally seen near the finely crystalline quartz-amphibole-schist, that forms the hanging-wall (see Fig. 172).

In this quartz vein, aggregations are very often found of a finely felted quartz-tourmaline rock, called carvoeira, in which andalusite also occurs at times. Other aggregations consist of garnet with biotite, pyrite and cyanite, as well as of a greenish oligoclase-albite.

The gold occurs either in beautiful crystals or merely in jagged or scaly flakes, filling the interspaces of the tourmaline rock, especially where the latter is rich in arsenopyrite. The gold carries a considerable amount of

[1] M. P. Ferrand: 'L'or a Minas Geraes,' Vol. II, pt. 1. Ouro Preto, 1894. E. Hussak: 'Der goldführende kiesige Quarzlagergang von Passagem, *Zeit. f. Prak. Geol.*, 1898, p. 345.

[2] Itabirite is regarded by some geologists as a mantle of residual sand cemented by limonite deposited by surface water, and merely a result of weathering. See 'Harrison's Report on British Guiana Laterites.'—W.

bismuth, which apparently is present in the form of an alloy. The highly auriferous arsenopyrite-tourmaline aggregations also carry small crystals of monazite and xenotime.

E. Hussak is inclined to consider the vein as of intrusive nature, and to regard it as an ultra-acid granite apophysis. In support of this view, he points to the presence of zircon, monazite, xenotim and albite, minerals that are characteristic of granite, and which occur as accessories in the quartz vein, and also to the presence of a large granite mass only 1 km. away. (Both Lindgren and Emmons maintain, however, that Hussak's facts prove it to be a normal fissure vein. See 'Genesis Ore Deposits,' p. 758.) The minerals tourmaline, andalusite, staurolite, cyanite, garnet, biotite, hercynite (iron spinel), which are also found in the vein, he regards as contact minerals, resulting from thermal metamorphism of the quartzite schist. His interpretation of this remarkable deposit is akin to the views of North American investigators on the relationship of certain gold quartz veins with pegmatites, mentioned on page 297. In many respects the veins in diorite and granite of Meadow Lake, California, resemble the Brazilian deposits just described. According to Lindgren,[1] these veins contain a quartz and tourmaline gangue carrying pyrite, arsenopyrite, pyrrhotite, blende and copper, besides gold.

Among the gold ore deposits in the Ural, the arsenical gold quartz formation includes the veins of Kotchkar[2], repeatedly described in recent times, situated in the steppe immediately adjoining the east slope of the mountains, in the Government of Orenburg. The region is underlain by sheared and decomposed granite. The vein filling consists of crushed and leached rock with cavernous quartz, particularly porous in the richer portions and carrying free gold, much arsenopyrite, somewhat smaller quantities of pyrite, and still more rarely manganite, copper pyrite, galena and stibnite. The arsenopyrite also impregnates the adjoining granite, which contains from 2.5 to 375 gm. gold per ton. The ore averages 8 to 10 gm. ($5.20 to $6.60) per ton. In the Transvaal the bedded veins of Kromdraai, north of Krugersdorp, belong to this class[3].

V. *The Cobaltiferous Gold-Quartz Veins.*

This class has been established to include the unique deposits which differ decidedly from all the gold-bearing types of veins thus far treated,

[1] *Am. Jour. Sci.*, Vol. XLVI, Sept., 1893.

[2] N. Wyssotsky: 'Les Gisements d'Or du système de Kotchkar dans l'Oural du Sud,' 'Guide des excursions du VII Congrès Géol. Intern.,' 1897, St. Petersburg. H. B. C. Nitze and C. W. Purington: 'The Kotchkar Gold Mines,' etc., *Trans.* Amer. Inst. Min. Eng., Vol. XXVIII, 1899. p. 24. Chr. T. Nissen: 'Einiges über das Goldvorkommen,' etc., bei Kotschkar, *Berg u. Hütten. Zeit.*, 1900, p. 121.

[3] G. A. F. Molengraaff: 'Géol. de la Rep. Sud. Africaine,' 1901, p. 34.

especially in the fact that the quartzy matrix is small in amount compared to the ores. The real carrier of the gold is in this case the cobalt mineral, smaltite.

According to H. Oehmichen[1] and Dörffel, this unusual occurrence of gold is found in the Middelburg district, northern Transvaal, along the Kruis river. The Lydenburg shales, part of the Cape formation, contain at this place intercalated eruptive sheets of aplite-like rocks and diabase, which are traversed by an east-west vein 2-3 cm. thick, dipping 60-70° south, whose chief and almost only filling is smaltite, the ore carrying 60-150 g. of gold per ton. The ore contains between 7 and 8% cobalt, with 0.5 to 1% of nickel. The aplite wall rock is sericitized and is also impregnated with ore.

A second and similar vein occurs 5 km. farther west and is also in diabase. This, the Laatste-Drift vein, has a gangue of auriferous quartz mixed with kaolin which holds smaltite and copper ores in bunches sometimes containing molybdenite. Erythrite, limonite and scorodite are secondary minerals found in the outcrop. The ores carry from 100-250 g. of gold per ton, of which only a very small part is native, while 90% of the gold is contained in the chalcopyrite. The smaltite contains almost no gold. As the specimens from these veins that have thus far come into our hands differ so much from all other types of gold quartz veins we have thought it necessary to place these deposits in a group by themselves. They form a transition from the gold ore veins to the true cobalt veins, and, in fact, pure, non-auriferous cobalt veins are also known to occur alongside of the gold-bearing ores at this locality.

17. The Silver-Gold Veins.

The veins of this class are of widespread distribution and include the greatest gold-producing deposits of the world[2]. The matrix of veins of this class is mostly quartz, but also includes lesser amounts of various carbonates, especially calcspar and rhodochrosite, and rarely small amounts of barite. The ores contain gold in various forms, viz.: native gold, auriferous pyrites and other sulphides, and very frequently various tellurides, especially nagyagite (the sulpho-telluride of lead, containing 6-13% gold), sylvanite, a gold-silver telluride and silver telluride. On the other hand, various rich silver minerals occur, such as argentite,

[1] H. Oehmichen: 'Goldhaltige Kobaltgänge in Transvaal,' *Zeit. f. Prak. Geol.*, 1899, pp. 271-274.

[2] See 'Concentration des Metallgehaltes zu Erzlagerstätten,' *Zeit. f. Prak. Geol.*, 1898, p. 416.

stephanite, proustite, pyrargyrite, etc., together with argentiferous galena, zinc-blende and more rarely copper pyrite, gray copper, native arsenic, bournonite, stibnite, realgar and orpiment.

All the examples of the various classes of veins thus far mentioned show a close geologic connection with Tertiary or late Mesozoic eruptive masses, especially andesites and trachytes, dacites and rhyolites. Their formation seems to be conceivable as an aftermath of the eruption of these magmas, eruptions whose only survival or lingering remnant of igneous activity is found in thermal springs and gas exhalations, genetically connected with the eruptions.

The transformation of the above named eruptive rocks into propylite seems to have been a concomitant phenomenon of the origin of those veins.

The silver-gold deposits of Transylvania have been carefully studied for a long time[1].

The deposits occur mainly in the mountain region rising from the flat Tertiary land north of the Maros and drained by the head waters of the Aranyos (that is to say, gold river), Szamos and Körös. The true nucleus of these "Transylvanian ore-mountains" consists of crystalline schists, which, however, are only seen outcropping in large areas in the northeast part of the region. Elsewhere they are covered and concealed by Permian, Triassic, Jurassic and Cretaceous strata, mainly limestones, and also by Tertiary beds. These rocks are cut and broken through by intrusive masses of andesites and dacites, trachytes and rhyolites, as well as basalts. The gold veins are connected with these igneous outbreaks, especially with stocks of the propylites just mentioned, which, as will be explained farther on, probably represent later andesites. The gold veins traverse both eruptive masses and the adjoining Tertiary strata.

Some of the gold deposits of Transylvania are especially characterized by an abundance of tellurides, especially at Nagyág, Offenbanya, Faczebanya and Fericiel. The telluride-bearing deposits of this country will be first

[1] General works upon this District: Frh. F. von Richtofen: 'Studien aus den ungarisch-siebenbürgischen Trachytgebirgen,' *Jahrb.* d. k. k. geol. Reichsanst, Vienna, 1860, pp. 153-277. B. von Cotta: 'Ueber Erzlagerstätten Ungarns und Siebenbürgens,' Gangstudien, IV, 1, 1862 (with E. v. Fellenberg). F. von Hauer and G. Stache: 'Geologie Siebenbürgens,' 1863. F. Posepny: 'Zur Geologie des siebenbürgischen Erzgebirges,' *Jahrb.* d. k. k. geol. Reichsanst, 1688, I, pp. 53-56. *Ibid.* 'Allgemeines Bild der Erzführung im siebenbürgischen Bergbaudistricte,' *Jahrb.* d. k. k. geol. Reichsanst, 1868, II, pp. 7-32. C. Doelter: 'Aus dem siebenbürgischen Erzgebirge,' *Jahrb.* d. k. k. geol. Reichsanst, 1874, I. *Ibid.* 'Die Trachyte des siebenb. Erzgeb.' Tschermaks *Mineral. Mittheil*, 1874, pp. 13-30. *Ibid.* 'Ueber das Vorkommen von Propylit und Andesit in Siebenbürgen,' same journal, II, 1880, p. 1. P. T. Weisz: 'Der Bergbau in den siebenbürgischen Landestheilen,' Also, *Jahrb.* d. k. ungar. geol. Landesanst., Vol. IX, part 6, 1891. Semper: 'Beiträge zur Kenntniss der Goldlagerstätten des Siebenbürgischen Erzgebirges,' *Abhandl.* d. k. preuss. geol. Landesanst. New series. Part 33, Berlin, 1900. L. Remenyik: 'Les Mines de Métaux de Hongrie à l'exposition Universelle,' Budapest, 1900.

described and afterwards those without tellurides. We begin with Nagyág.

The mining town of Nagyág[1], in the Hunyadi Comitat, lies in a narrow gorge in the midst of a magnificent mountain region, near Mount Hajto, 1,047 m. (3,335 ft.) high. The surrounding heights all consist of andesitic and trachytic rocks, part of the eruptive chain of the Transylvanian Erzgebirge, which also contains various other mines of ancient and modern times, such as Coranda, Magura, Füzesd, Boicza, Trestia, Porcura, Zrdaholz and Ruda. On the valley bottom, and in the deep mine workings, there are exposures of the sedimentary rocks, broken through by the eruptive masses. These stratified rocks consist of yellowish sandstones and conglomerates, as well as gray and reddish clays, all of Mediterranean age, and with highly disturbed stratification. Large detached blocks of these sediments are enclosed by the andesites in the mining area. At still greater depth, phyllite-like schists are suspected to exist, being indicated by the inclusions of such phyllites in the andesites. The stratified rocks but very rarely, however, form vein walls, the deposits being almost entirely in Tertiary eruptive rocks. Two types of these eruptives outcrop at Nagyág. Their age is regarded as Miocene, since fragments of them are found in the Sarmatian (upper Miocene) limestones of Vormaga.

The neighboring eminence of Mount Calvary is formed of a quartz-free hornblende-andesite. In the immediate vicinity of the veins, on the other hand, the prevailing rock is a quartz andesite or dacite with biotite and hornblende, as well as augite, in greatly varying quantity. The latest monograph on Nagyág, by B. von Inkey, following Szabo's nomenclature, designates both rock types as trachytes.

The Nagyág dacite has been affected by three different kinds of alteration: (1) Normal weathering or decomposition on the surface, (2) by a propylitization or alteration into 'greenstone trachyte,' with formation of secondary chlorite and of carbonates from augite and hornblende, with accompanying introduction of gold-bearing pyrite, (3) by kaolinization. The two last named processes, certainly the kaolinization, seem to be genetically connected with the formation of the mineral veins. (See 'Thermal metamorphism.') The propylitization is most intense and widespread in the middle and lower parts of the eruptive stock, a place that is also the site of the ore deposits. The kaolinization of the rocks is still more

[1] Frhr. von Hingenau: 'Geol. bergmänn. Skizze des Bergwerkes Nagyág,' *Jahrb.* d. k. k. geol. Reichsanst., 1857, pp. 82-143. B. von Cotta: 'Ueber Erzlagerstätten Ungarns und Siebenbürgens.' Gangstudien, Vol. IV, part 1, 1862. F. von Hauer and G. Stache: 'Geologie Siebenbürgens,' 1863. H. Höfer: 'Beiträge zur Kenntn. der Trachyte und der Erzneiderlage von Nagyág,' *Jahrb.* d. k. k. geol. Reichsanst., 1886, p. 1. G. vom Rath: 'Vöröspatak und Nagyág,' *Sitzb.* der niederrh. Ges. f. Natur- und Heilk. in Bonn, March, 1876, and March, 1879. B. von Inkey: 'Nagyág und seine Erzlagerstätten,' Budapest, 1885.

intimately connected with the veins, as is apparent from the cross-section, Fig. 173.

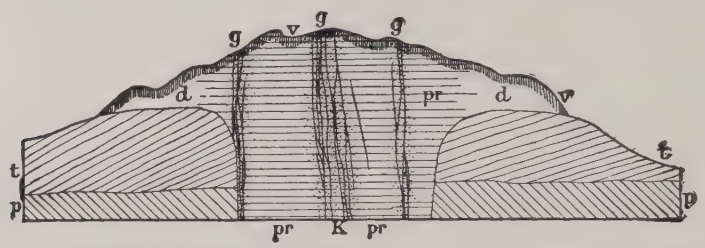


Fig. 173.—Diagrammatic cross-section through the veins of Nagyág. (B. von Inkey.)
p, phyllite; t, tertiary sediments of the Mediterranean stage; d, dacite; pr, propylite; g, vein streaks; k, kaolinized dacite; v, superficial weathered cover.

Another peculiarity of the Nagyág district that needs mention is the presence of 'barren' veins (Glauchgangue), a feature which is also known in other Hungarian and Servian ore deposits in propylitic rocks, as for example at Vorospatak, where they are called 'glamm.' The 'barren'

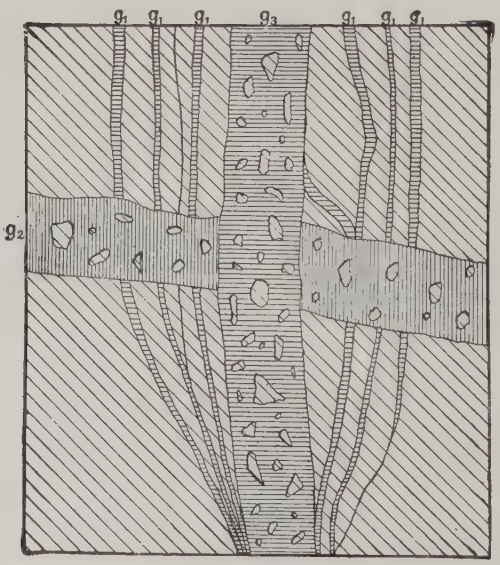


Fig. 174.—Horizontal plan of barren veins at II Longin at the 75 fathom level at Nagyág. (B. von Inkey.)
g_1, oldest barren veins ; g_2, second barren vein, dark 20 cm. thick; g_3, youngest barren vein, light gray, 15 cm. thick.

veins of Nagyág cut through the propylite and the blocks of Tertiary rocks enclosed by it. The fissures vary from mere cracks up to 10 or even 20 m. in thickness. They are filled with a dark sandy or clayey mass, con-

taining angular or sub-angular fragments of the adjoining rock. These 'barren' veins cut one another and are thus shown to be of different ages. Fig. 174, after B. von Inkey, shows as many as three sets of these Glauchgange differing in age. The included fragments can often be shown to be torn from portions of the wall rock 10 m. (32.8) to even 20 m. (65.6 ft.) distant. This displacement appears to be even greater since bits of phyllite are not infrequently encountered, which seem to have been brought up from a greater depth. The 'barren' veins are explained in various ways. Some authors regard them as fault fissures, filled with friction breccias and the finer products of attrition. This view is, however, opposed by the fact that very many 'barren' veins show no dislocation whatever in the adjoining rock. F. Posepny for some time thought of an in-washing of the material from above. This is hardly conceivable, however, in view of the fineness and manifold ramification of the network of the 'barren' veins. H. Hofer and others supposed them to be decomposed and crushed dikes of eruptive rock, but this is not confirmed by the petrographic character of the finer material composing the filling. B. von Inkey, who seems to have devoted much attention to these phenomena, notes "that the débris material in the Glauchgange breccia is evidently derived from the fissure walls, while the matrix, which is a mixture of fine sand with clay, was originally a watery mud, whose solid particles may be derived partly from the dust particles produced by the comminution of the adjoining rock, and in part represent triturated material of deeper rocks. The water which made mud of this dust is supposed to be derived from the ground-water of the rocks of the Mediterranean stage. When afterward a mighty eruption fissured these strata and forced great wedges of a hard rock between them, the subterranean water circulation was altered, the passage of the ground-water was checked and dammed back, and large accumulations of water or even of thin liquid mud, were formed beneath the trachyte cover and between the eruptive wedges." He next imagines that the mass of the eruptive stock, through the yielding of its sedimentary base and its lateral supports, became fissured, and that thereupon those masses of mud were forced by high pressure from below into these collapse-fissures[1].

The mineral veins found within the stock of propylitized dacite, at Nagyág, form a tangled network of fissures showing great variety in thickness and direction. Most of the fissures, however, strike about north-south. Minute veinlets and veins ½ m. thick fray out, gather into clusters or cross one another in the most diverse manner, though apparently all belonging to the same period of formation. According to B. von Inkey, the veins are not contraction fissures, but are due to external orogenic causes.

[1] B. von Inkey: A. a. O., p. 149.

Classified according to the nature of their ores, Freiherr von Hingenau at an early date was able to distinguish three areas, each characterized by its own peculiar distribution of the prevailing vein minerals, a conclusion confirmed in general by H. Höfer and von Inkey. These three districts are the following:

(a) The region of telluride-carbonate veins, with calcite, siderite, dolomite and rhodochrosite, some quartz and hornstone with alabandite (Mn S), nagyagite and other tellurides of gold, also some tetrahedrite and pyrite; the latter, it is true, merely as an impregnation in the adjoining rock. This is in the southeast part of the district, mainly below Mount Szekeremb, extending as far as the Anastasia cleft.

(b) The telluride quartz veins or rich quartz area whose veins carry gray, non-crystalline, often cellular quartz, with auriferous sylvanite, krennerite, gray copper and rarely free gold. This area is in the northeast parts of the district and near Mount Hatjó.

(c) The area of the sulphide ores, which pass into the two other classes by gradual transitions. It is marked by the prevalence of galena, zinc-blende and pyrite in a gangue of carbonates, in which argentiferous tetrahedrite occasionally appears.

The subordinate minerals of the Nagyág veins include gypsum, which sometimes encloses flakes of native gold, native arsenic, bournonite, stibnite, plumose jamesonite, realgar and orpiment, all of which occur mainly in the upper parts of the veins.

An enrichment of the veins is generally found to occur when strings of pyrite cross the fissures, and when the veins themselves form intersections, or when in contact with the 'barren' veins (Glauchgange), which in such cases they either traverse or follow as a network of stringers. When the ore-bearing veins ramify in a large mass of barren vein matter the result is a "Trümerstöcke" (stringer stock), as it is called, such as the Philipp and the Adam stock. Neither a diminution of the gold content or a wedging out in depth has thus far been observed at Nagyág.

The Nagyág goldfield was the last of the Hungarian-Servian mineral districts of the region to be discovered, being found in 1745. Mining operations began in 1748 and have continued in a flourishing condition ever since, the mines being in part the property of the crown and of the state treasury. It may be mentioned that it was in the Nagyág gold ores that the element tellurium was discovered in 1782 by Muller von Reichenstein.

At Offenbanya[1], which is situated in the valley of the Aranyos, on the

[1] J. Grimm: 'Die Erzniederlage und der Bergbau zu Offenbánya in Siebenbürgen,' *Jahrb.* d. k. k. Montan-Akademien, XVI, 1867. F. Posepny: 'Ueber den inneren Bau der Offenbányaer Bergbaugegend,' *Verh.* d. k. k. geol. Reichsanst., 1875, IV, p. 70.

north border of the Transylvanian Erzgebirge, two classes of deposits are distinguished: (1) Contact deposits, occurring at the contact between intercalated beds of crystalline limestone in the garnetiferous mica schist and Tertiary dacites and hornblende andesites; (2) mineral veins.

The contact deposits locally called lead stocks are formed of pyrite, zinc-blende, arsenopyrite and galena imbedded in a calcareous matrix, and the deposit shows no connection with the gold veins. They were formerly mined by the state, but are now of no importance.

The mineral veins occur in a stock of dacite. Where they pass into a mass of friction breccia, developed locally along the contact between the eruptive rock and the mica schists and limestones, most of the veins wedge out. They are of very small thickness, mostly only 5 to 25 mm., and can only be followed 130 m. in the strike.

Some of them carry only native gold, some only telluride ores, others carry both at the same time. The matrix consists of quartz and calcspar. The more quartz the fissures carry, the richer they are in tellurides (sylvanite and nagyagite). The subordinate accompaniments of the tellurides are pyrite, zinc-blende, realgar, more rarely proustite, bournonite, tetrahedrite, marcasite and arsenopyrite. In druses, crystals of quartz, calcspar, barite, aragonite, albite and gypsum are found. In certain veins, free from tellurides, wulfenite, pyromorphite, as well as stibnite, were also found.

Most of these fissures have a general east-west course. The vein wall-rock is thoroughly decomposed and impregnated with small crystals of auriferous pyrite, so that zones of this altered rock, 5-8 m. (16.4 ft. to 23.2 ft.) broad, are mined as gold ore, and where several fissures meet or come close together great masses of rock have been impregnated with gold, the deposit resembling the so-called gold quartz stock of Nagyág.

Since mining has been resumed the work has been confined mainly to one such stock, the so-called Kreisova stock. This consists of a crushed or brecciated dacite in which the veins consist of drusy quartz with pyrite and silver ores, gray copper, copper pyrite and galena. The amount of silver and gold is stated to be very considerable.

Verespatak occupies the first rank, among the telluride bearing districts, not so much because of its present production as because of its historic fame.[1]

[1] F. von Hauer: 'Der Goldbergbau von Vöröspatak,' *Jahrb.* d. k. k. geol. Reichsanst., 1851, IV, p. 64. J. Grimm: 'Einige Bem. über die geogn. und bergbaul. Verh. von Vöröspatak,' *op cit.*, 1852, III, p. 54. F. Posepny: 'Einige Resultate meiner bisherigen Studien über Verespatak,' etc. *Verhandl.* d. k. k. geol. Reichsanst., 1867, p. 99, 1870, p. 95 and 1875, p. 97. G. vom Rath: 'Vöröspatak und Nagyág,' *Sitzb.* der niederrhein. Ges. f. Natur- und Heilkunde in Bonn, March, 1876. F. J. Kremnitzki: 'Beobachtungen über das Auftreten des Goldes im Verespataker Erzreviere,' Földtani Közlöny, 1888, pp. 517-520. Also the works noted on p. 331; particularly the work of Semper, pp. 125-172.

This place is situated in a deep valley about 10 km. (6 miles) northeast of Abrudbanya. B. von Cotta called it the Eldorado of Transylvania, and even to-day 172 small companies are busy in this region, and the waters from 5 reservoirs drive over 6,000 stamps. Back of the town and to the south of it lies the famous Csetatye, a bald, rocky ridge, completely honeycombed by mining works, which have been carried on from Roman times, A. D. 106-276, down to the present day.

The Verespatak mineral area is an isolated mass consisting mainly of eruptive rocks lying in the midst of the monotonously uniform Carpathian sandstone (Cretaceous and Eocene). This mass consists of dacite, rhyolite, and rhyolite breccias, the latter often silicified. It forms the two mountain stocks of Kirnick and Boi. The great Csetatye mentioned above consists in part of this dacite, which carries large dihexahedrons of quartz, in part of the silicified rhyolite breccia. Younger Tertiary sediments, namely conglomerates, sandstones and tuffs with rhyolitic material in them, are also found there.

A very remarkable feature of the district is the occurrence of the so-called 'glamm' veins, which form a network of fissures throughout the district. Their filling consists of a clayey mass containing rounded rock-fragments, including pieces of coal of considerable size, trachyte fragments and bits of mica schist and phyllite. These masses are impregnated with pyrite and limonite, and seem to have been pressed into the fissures with great force, apparently from below. Semper thinks them intrusions of volcanic mud.

The ore-bearing veins occur partly in the eruptive masses and partly in the above mentioned sediments. In the Carpathian sandstone the veins contain practically only quartz with free gold. Elsewhere the quartz and free gold are accompanied by banded rhodonite, calcite, calcspar, rhodochrosite, gold-bearing pyrite, zinc-blende, as well as galena, gray copper and seldom adular spar. The gold occurs in crystals intergrown with rhodonite and quartz. In the heart of the Csetatye ridge the gold-bearing fissures form a stock of rich stringer veins, called Katronza (petticoat), whose extraction has left great excavations. Similar stringer vein stocks were worked as early as Roman times. They commonly consist of eruptive breccia impregnated and cemented by gold-bearing pyrite and quartz.

A similar deposit is found at Bucsum, about 10 km. southeast of Abrudbanya, in the mines of the Concordia company.

The Vulkoy Korabia and Botes[1], mining districts about 15 km. north of Zalathna, which are similar, were also known to the Romans. The veins occur partly in the trachyte, partly in the Carpathian sandstone. Their

[1] Fuchs and de Launay: 'Traité,' II, p. 932. Semper, *op. cit.*, pp. 178-181.

filling consists mainly of quartz with fine sprinklings of free gold, besides gold-bearing pyrite, and a little chalcopyrite, gray copper and galena. The gangue carries hessite.

The largest gold mines that are being worked at the present time in Transylvania are situated near the town of Brad, the Twelve Apostles[1] and Muszari mines, and at Boicza, all of which are located in the western part of the gold area.

An extraordinary excitement was recently created by the great success of the Geisslinger Industrial Company in the Muszari mine near Brad[2], which in 1895 produced 732 kilograms of crude gold (gold-silver). The entire workings lie in a massive of andesitic and dacitic rocks. Two systems of veins intersect at right angles with very rich orebodies at the crossings, as, for example, that between the Clara and Karpin veins, from which, in 1891, 53 kilograms of crude gold were taken. The vein filling at this place consisted of quartz, calcspar, pyrite and some light-colored zinc-blende. The Clara vein sends out several lateral stringers, which gather and ramify in the Clara stock. This stock, varying up to 7 m. thick, is interspersed with druses containing quartz, pyrite and free gold. The ores in this "treasure chest of Muszari" contained in places as much as 1,000 gm. per ton. This space, which is enclosed by an iron grating, yielded about 600 kg. of gold in 1¾ years.

The other veins of this mine have a thickness of 2 cm. to 2 m., and carry a gangue of quartz and calcspar each in varying amount with gold-bearing pyrite, free gold, sphalerite, chalcopyrite, marcasite, arsenopyrite and some galena. The latter does not seem to have a favorable effect on the gold contents. The amount of gold in the veins varies from 9 to 30 gm. per ton.

The last Hungarian locality to be mentioned as illustrating this class of deposits is that of Boicza, near Déva, in the district of Brad, whose mines are of great importance[3]. The veins are found in a stock forming the Szvregyel mine, which is about 1 km. from the place itself. The core of this mountain is formed of a rock which is regarded by Primics as a melaphyre, whose age lies between lower Triassic and upper Jurassic. This makes it older than the Tithonian limestone which apparently overlies it in many places. According to other authors, the rock is much younger, belonging to the andesitic group. This older eruptive mass is broken through by a spreading stock of dacite, especially broad in the upper part of the moun-

[1] See Semper, *op. cit.*, pp. 86-109.

[2] According to a communication received from H. Oehmichen.

[3] Primics György: 'Die Geologie des Csetráser Erzrevieres' (Hungarian), Budapest, 1896. L. Venator: 'Monogr. über das Gold- und Silberbergwerk Rudolfi in Boicza,' Hermannstadt, 1900.

tain. This dacite encloses numerous fragments of the melaphyre and the Tithonian limestone along the contact zone.

The gold veins occur chiefly along the contact between the two eruptive rocks, but in part also within the melaphyre. They strike northwest and dip 75 to 85° in two different directions. Two systems may be distinguished, whose principal veins show a tendency to unite into a single vast fissure, the so-called stock, in the southeast part of the mineralized district. The two main fissures, Schuhaida and its companion, the Kreuzschlager vein, show payable ore for a length of 800 m. (2,624 ft.) The veins are not thick, varying between 0 and 1 m., the average being 0.35 m.

According to L. Venator, the filling, which differs considerably from vein to vein, consists mainly of quartz, in which gold-silver, calcspar, barite, rhodonite, amethyst, pyrite, chalcopyrite, galena, sphalerite, argentite and proustite occur. In most of the fissures, pyrite predominates over the other ore minerals, though in some veins galena and zinc-blende are the chief ores. The gold (which contains much silver) occurs in microscopic grains scattered through the ore and it is only in the very richest ore that it is visible to the naked eye. At times the gold is associated with pyrite, more rarely with zinc-blende. The vein junctions and intersections are here followed by distortion and not by ore shoots and enrichments, these being, however, sometimes found at some distance beyond the intersections. The ore 'stock' is due to the meeting of many of the veins. It attains 40 m. in longitudinal and 30 m. in transverse diameter, at the 110 m. level. Its filling consists sometimes of fragments of melaphyre and dacite, cemented by an ore-bearing material, which at some points is very rich.

As is known from various archeologic discoveries, mining operations were carried on at Boicza as early as Roman times. About the year 1444 the work was resumed, but not until 1884 did modern mining begin. In 1898, 212,436 kg. of fine gold and 171,700 kg. of silver were produced.

This brief summary of the Dacian gold districts has shown that less than half of them can be assigned to the typical silver-gold-veins, since the majority of them just described contain tellurides. All of them are, however, of the same age, are genetically dependent on masses of Tertiary eruptive rocks of the andesite and trachyte families, and show so many other geologic characteristics common to all that they can not well be separated in the classification adopted.

A second region containing similar deposits is that of Schemnitz[1] (in Hungarian, Selmeczbanya) in the Erzgebirge of lower Hungary.

[1] Beudant: 'Voyage minéralogique et géologique en Hongrie,' Paris, 1822. Frhr. J. von Richthofen: 'Studien aus den ungarischsiebenbürigschen Trachytgebirgen,'

This long-famed mining region, whose mining work probably dates back to the eighth century, and which, as the seat of an old mining academy, has always had keen intellectual men watching its development, is, geologically, one of the best-studied mining areas of the globe. The older pioneer works of Esmark, Beudant and Pettko were followed by the more recent ones of von Richthofen, von Cotta, Lipold, Szabo, Cezell, Csch and H. Böckh, of which we are only able to cite some of the more important. According to the recent work of Böckh, the oldest formation in the vicinity consists of Triassic slates which, along their contact with diorite, are altered to gneiss-like hornstone and mica schists. The Trias also contains limestones and quartzite. After this come Eocene Nummulitic shales. The series of eruptions began between the time of the lower and upper Mediterranean stage. These eruptions were the cause of the vein and ore formation of the district. At first pyroxene andesite, then diorite and granodiorite (quartz diorite), next aplite, then biotite and amphibole-andesite and finally rhyolite. Much later in the Pliocene period basalt eruptions occurred. The rhyolites are predominant and show very diverse modifications, besides forming obsidians, perlites and pumice stones. Furthermore, it happens that just in the region of the ore veins the various trachytic and andesitic rocks have experienced a very widespread hydatometamorphic alteration into propylites, locally called greenstones or greenstone-porphyries. The propylite is, however, no longer regarded as an independent rock of older age than the porphyries, as at one time maintained by F. von Richthofen. The rocks carry much pyrite and are silicified near the veins. Besides andesite flows there are also tuff-like accumulations, trachyte breccias and trachyte conglomerates, which sometimes enclose fragments of coal torn off from Tertiary strata broken through by the eruptive rocks.

The lodes occur in exceedingly great numbers. The strike of most of them is between north-south and northeast and the dip is steep, more frequently southeast than northwest. The vein fissures traverse not only the trachytic and andesitic rocks, but in their southwest continuation they cut Miocene strata. They are for the most part of considerable thickness, usually being compound lodes without clearly defined walls. They enclose a good deal of material from the adjoining wall rock, which is decomposed

Jahrb. d. k. k. geol. Reichsanst., Vol. XI, 1860, pp. 153-277. B. von Cotta: 'Ueber Erzlagerstätten Ungarns und Siebenbürgens,' 1862, pp. 28-41. M. V. Lipold: 'De Bergbau von Schemnitz in Ungarn,' *Jahrb.* d. k. k. geol. Reichsanst., 1867, Vol. XVII, pp. 317-458; with bibliography. J. W. Judd: 'On the Ancient Volcano of Schemnitz,' *Quart. Journ.* Geol. Soc., August, 1876. 'Die Erzgänge von Schemnitz und dessen Umgebung,' official map, 1883, written by von J. Szabó, L. Cseh and G. Gezell. J. Szabo: 'Geschichte der Geologie von Schemnitz,' announcement, 1885. *Idem:* 'Monographie der Umgebung von Schemnitz.' H. Böckh: 'Ueber das Altersverh der in Umg. von Selmeczbánya vork Eruptivgesteine,' *Földtani Közlony*, Vol. XXXI, 1901.

into clay or is silicified. The prevailing gangue consists of quartz, amethyst and hornstone; other minerals, usually of later formation, include calcspar, brownspar, rhodochrosite, siderite, barite and gypsum. The most common ore minerals are argentiferous galena, zinc-blende, chalcopyrite and auriferous pyrite, which occur scattered through a gangue of quartz and jasper-like material, this ore being called zinopel. Besides the zinopel, there are found rich silver ores, such as native silver, argentite, stephanite, polybasite and pyrargyrite, at times also native gold. Rarer occurrences are, among others, stibnite, hübnerite, tetrahedrite, marcasite, pyrrhotite, copper glance, cinnabar, fluorspar, diaspore and adular spar.

Most of the veins occur (1) in the andesites and rhyolites and (2) in diorite. Among the lodes in the andesite rock we may mention the Grüner, Stefan, Johann, Spitaler and Biber veins, while of the second group, which

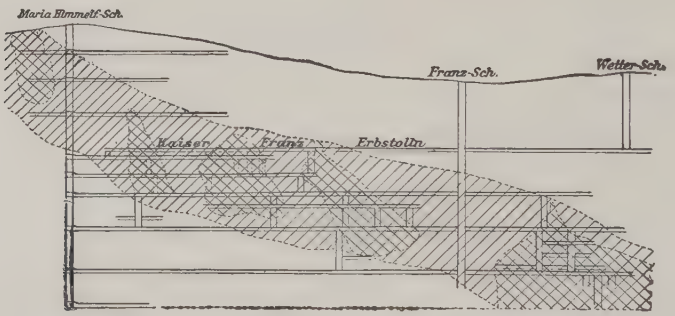


Fig. 175.—Horizontal section of the Grüner lode at Schemnitz. Showing the ore shoots forming a continuous zone of enrichment. (G. Faller.)

is developed at Hodritsch, west-northwest of Schemnitz, we may mention the Allerheiligen, Josefi, Schöpfer and the Brennerstolln lodes.

As representatives of the first group, the Grüner and the Spitaler veins may be characterized in a few words.

The Grüner vein has been traced for a distance of 1.5 km. (0.9 mile). The course is northeast, the dip 70 to 80° southeast, and the thickness 2-12 m. (6.5-39 ft.). The larger part of this great fissure is usually filled with much-crushed and pyritized rhyolite, which is traversed by stringers of ore forming compound veins. The ore is characterized by the great predominance of the true silver ores over galena and blende. The most abundant ore mineral is stephanite with associated argentite, polybasite and a little native silver, all of which, intergrown with pyrite crystals, occur in a grayish densely crystalline or drusy transparent quartz mixed

with carbonates. The pay ore occurs in flat ore shoots or columns, whose horizontal extent is but 40 m. (131 ft.), but which extend downward much farther. These shoots have a flat pitch southwest as shown in the sketch (Fig. 175). Outside of the ore shoots the vein is much lower grade, though not barren.

The Spitaler vein is the most important of the entire area. It has been traced for a distance of over 8 km. (4.8 miles) and may have a total length of over 12 km. (7.2 miles). The course is mainly north-northeast, the dip south-southeast at 32 to 70°, being steeper with increasing depth. The vein is very thick, averaging 40-50 m. (131-164 ft.), which, however, does not mean that this is a single vein fissure. On the contrary, it is a lode formed of a system or cluster of veins consisting of single veins and stringers, very close together, but separated by layers of barren material. At points where the stringers converge, the lode attains a thickness of as much as 5 m. The gangue is principally quartz, with some rhodochrosite, calcite, brownspar and barite. The ore throughout the greater part of the lode consists of auriferous and argentiferous galena, blende, copper pyrite and pyrite, with a little free gold and rarely some cinnabar. In the southwestern region, the lode assumes quite a different character, rich auriferous silver ores being predominant.

The lodes of the second group cut the diorite at Hodritsch. They contain rich silver ores in a gangue of quartz and carbonates. The adjoining rock is strongly impregnated with pyrites.

The Schemnitz mines are the oldest in central Europe. According to some authors, the Quadi at "Vania," in this vicinity, had mines as early as the beginning of our era. About 745 the mines passed into the possession of the Slavs, who continued to work them. Their rights were left undisturbed by the Magyars, who came into power at the beginning of the 10th century. The names of the mines, moreover, indicate that there were numerous immigrations of Germans, especially Saxons from Meissen. They infused new life into the operations and the Germans monopolized the mines under Andrew II. Under Bela IV (1235-1270) the town was granted municipal and mining rights under the name of Schemnitz (Sebnitz). The first chair of the Mining Academy was established in the year 1763[1].

The Schemnitz lodes are similar to those of Kremnitz[2] (Körmöczbánya), situated farther north. The latter also are associated with propylitized

[1] 'Gedenkbuch zur hundertjährigen Gründung der k. ung. Berg- und Forstakademie in Schemnitz,' 1871.

[2] E. Windakiewicz: 'Gold- und Silberbergbau zu Kremnitz in Ungarn,' *Jahrb.* d. k. k. geol. Reichsanst., 1866, Vol. XVI, p. 217.

trachytic rocks. The ores occur in wide lodes composed of stringers and not in a single fissure. The ores and vein stone are exactly like those of the Schemnitz lodes.

A third Hungarian district distinguished by silver-gold veins is found in the Wihorlet-Gutin mountains, along the boundary line between the Marmaros, Szatmar and Ugocsa comitates. This mountainous tract, which rises steeply to a height of 1,500 m. above the great Hungarian plains to the west, consists of trachytes, rhyolites and dacites in part of propylitic habit. In the Nagybánya region, at Kreuzberg, 1 km. north of the town, at Veresviz (meaning red water) 3.5 km. northwest, at Felsöbánya on the east, and farther off at Turcz, Negy-Tárna, Visk, Illoba, Laposbánya and Miszabánya and at Borpatak and Kapnik, these rocks are traversed by lodes quite similar to those described at Schemnitz. For further details the reader is referred to G. Szellemy's comprehensive work[1].

These silver-gold deposits of Transylvania and lower Hungary, which have been so briefly summarized or merely mentioned, all form a geologic unit. They are associated with vast eruptions of trachyte and andesite, which took place along the inner side of the mountains formed by the great Carpathian anticlinal uplift. Thus they are a final consequence of the shrinkage of the earth's crust. The molten matter rose along a basin formed by the one-sided nature of the mountain-folding, forming intrusive and extrusive masses. These eruptions were followed by the formation of fissures through which the metallic materials from the still hot masses of the interior could be conveyed in solution and deposited in the upper part of the earth's crust. Entirely similar phenomena occur in western North America.

The Great Basin of Utah and Nevada, lying between the Sierra Nevada and the Rocky Mountains, was the theatre of tremendous volcanic activity in Tertiary time. Immense quantities of lava were poured out from the interior of the earth, forming lava flows many miles in length, or spreading out in great sheets and forming monotonous plains. Craters are recognizable at many points, the vents being surrounded by vast tracts of land covered with the ejecta of the volcanoes, either as loose lapilli and cinders or firmly cemented. Erosion and denudation have dissected these volcanoes, exposing the cores as great 'stocks,' whose rocks mostly belong to the andesite family. These volcanic centers and their immediate environs are the seat of numerous vein-like deposits of silver-gold ores. The greatest and most famous is the Comstock lode, situated in the Washoe district in Nevada.

[1] Geyza Szellemy: 'Die Erzlagerstätten von Nagybánya in Ungarn,' *Zeit. f. Prak. Geol.*, 1894, pp. 265-271, 449-457; 1895, pp. 17-25.

The Comstock Lode.—This famous deposit has been the object of careful and repeated examination by various scientific observers[1].

The geologic conditions may be generalized as follows: A huge stock, whose highest point forms Mount Davidson, consists of pyroxene andesite, whose upper part is of normal andesitic habit, and contains porphyritic crystals in a partly glassy groundmass. In depth this rock gradually as-

Fig. 176.—Outcrop of the Comstock lode, Nevada, showing location of the mining claims.

sumes a granular structure so that the crystalline rocks thus developed, which are badly changed by a secondary propylitic alteration, apparently

[1] F. v. Richthofen: 'The Comstock Lode,' San Francisco, 1866. Clarence King: 'U. S. Geol. Explor. of the 40th Parallel,' Vol. III, *Min. Ind.*, Washington, 1870. J. A. Church: 'The Comstock Lode, its formation and history,' *Trans.* Am. Inst. Min. Eng., New York, 1879. G. F. Becker: 'Geol. of the Comstock Lode,' etc., U. S. Geol. Surv., *Monogr.* III, 1882. E. Lord: 'Comstock Mining and Miners,' U. S. Geol. Surv., *Monogr.* IV, 1883. A. Hague and J. P. Iddings: 'On the development of crystallization in the igneous rocks of Washoe,' *Bull.* U. S. Geol. Surv., No. 17, 1885.

differ so much from the andesite that they were formerly described as diabase or granular diorite. Farther east pyroxene-andesite is intruded by a huge mass of mica-hornblende-andesite, formerly called porphyritic diorite. On the east flank of Mt. Davidson this rock has overflowed the pyroxene-andesite, and like it, passes downward into granular-crystalline varieties, the deep-seated facies being formerly called mica diorite. This mica-horn-

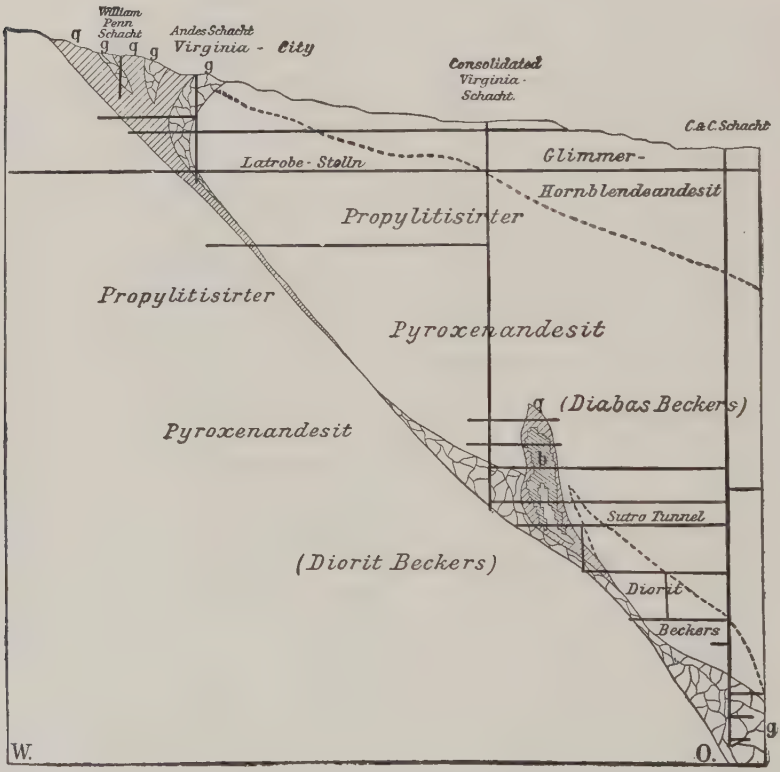


Fig. 177.—Cross-section through the Comstock lode. (Becker.)
g, lode body; q, quartzose lode mass; b, excavation in the bonanza.

blende-andesite has also undergone partial propylitization. The study of Becker's thin section by Hague and Iddings convinced them that the various Comstock rocks discriminated by older authors and assumed to be partly pre-Tertiary and partly Tertiary, may be referred to the two Tertiary andesite magmas mentioned, which were possibly intruded at approximately the same time. Furthermore, in the mines of that locality a great number of younger dike-like or stock-like intrusive masses of mica-hornblende-ande-

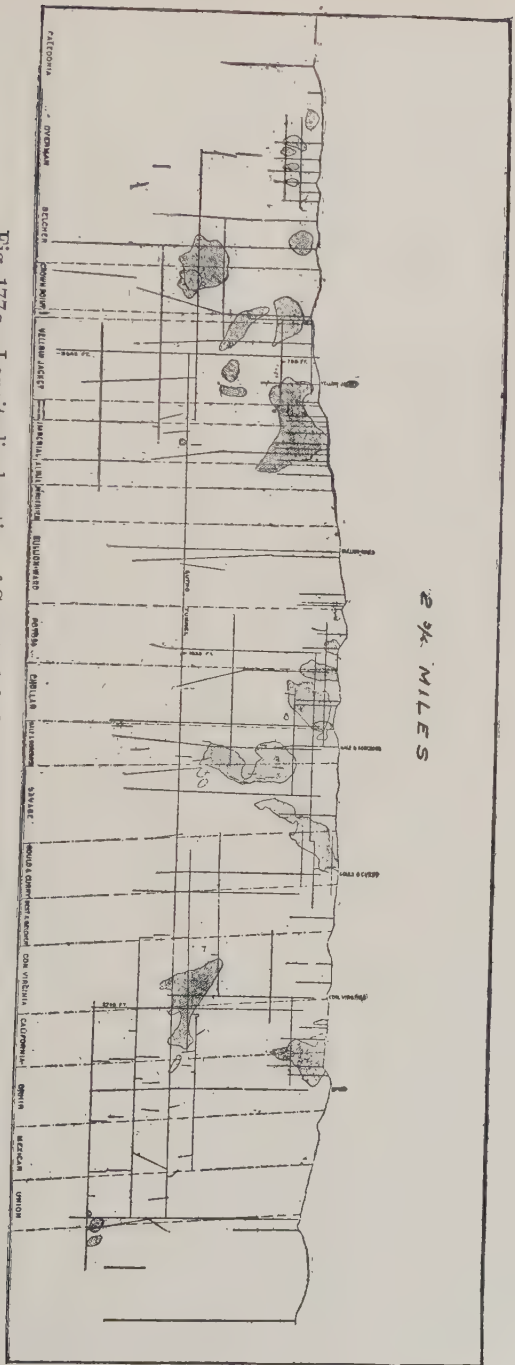


Fig. 177*a*.—Longitudinal section of Comstock lode, Nevada, showing ore shoots. (Becker.)

site, dacite and rhyolite (formerly called quartz porphyry) and of basalt have been met with.

The Comstock lode has a north-northeast course, and dips at 45 to 50° east-southeast. The lode occurs approximately but not always exactly at the boundary between the altered pyroxene and the mica-hornblende andesites just mentioned. It is a zone of faulting of greatly varying thickness. The upper part of the lode near the outcrop is exceedingly wide, but consists mainly of completely altered country rock, often decomposed into clay. In this, the main body of the lode, there is observed a hanging-wall vein and a foot-wall vein, the latter very large and of very irregular shape. In the cross-section, Fig. 177, taken from Becker's atlas, the orebodies are seen to be great lenses, dividing into two parts, and very irregular in outline.

These lenses and ore shoots have in part a course transverse to that of the lode itself, and sometimes extend far beyond the lode wall. F. Posepny[1] has very wisely suggested that this may be due to cross fissures.

These orebodies consist mainly of quartz. If we consider that the quartz orebodies and the decomposed rock form a unit, the entire lode has an average thickness of 60 to 100 m. (196 to 328 ft), and extends for a distance of nearly 2 miles. The vein divides at each end into several branches; including these its outcrop has been traced more than four miles (7 km.).

The quartz ore shoots just mentioned usually carry considerable gold and silver, and are but rarely barren. The ores include stephanite, polybasite, argentite, native gold, some galena and sphalerite, all of which occur in minute particles distributed through the friable quartz. The ore minerals also occur concentrated into very rich bonanzas. But small amounts of calcspar, gypsum and zeolites are found mixed with the quartz. Near the outcrop the bonanzas were rich in 'horn silver' (silver chloride), as, for example, the one encountered in 1874, which was 360 m. (1,180 ft.) across. The bonanza ores averaged 0.001 to 0.5% of gold, and 0.05 to 1.78% silver. Notwithstanding the large dimensions and rich contents of the various bonanzas, it must not be forgotten that they formed but a very small part of the entire mass of the lode, amounting to only about 1:600, according to Burthe. Nor do they show any definite rule or arrangement in the lode. At any rate this lode was, to quote Ed. Suess[2], "the greatest accumulation of precious metal that man ever laid hands on." From 1859 to 1889 the Comstock lode produced 4,820 tons of silver and 214 tons of gold, of a

[1] F. Posepny: 'Genesis der Erzlagerstätten,' *Jahrb.* d. k. k. österr. Bergak. 1895, p. 124.

[2] E. Suess: 'Die Zukunft des Silbers,' Vienna, 1892.

total value of $340,000,000 (J. Vogt). In brief, the history of the lode is as follows: As early as 1856 gold gravels were discovered and washed near the lode. The lode itself was discovered in 1857 by the Grosh brothers. It was first worked, however, by others in 1859, for free gold only. The silver ore was not recognized for a while, but soon after its discovery it became the main object of mining. The towns of Virginia City and Gold Hill rose like magic on the flanks of the desert! Deeper and deeper the work penetrated until great difficulty was encountered in keeping the mines dry. In 1878 the famous Sutro tunnel completed draining the mines to its level. With increasing depth, however, mining became more and more difficult, owing to the increasing heat, until in 1877, in the shaft of the Savage mine at a depth of about 900 m. (2,950 ft.), a spring with a temperature of 69.4° C. (157° F.) was tapped[1]. This put an end to any downward advance.

The Veta Madre, of Guanajuato, Mexico, is very similar to the Comstock in its structure and ores, belonging to the same type. Its production has far exceeded that of the Comstock, but has been spread out over a period of 300 years. It is described on page 266 as a silver vein.

A somewhat more pyritic example of the silver-gold formation, also associated with andesitic rocks, is represented by the Smuggler[2] vein, near Telluride, in the San Juan Mountains, in Colorado. While the Comstock Lode was characterized by rich bonanzas distributed in a capricious way, the Smuggler lode shows great uniformity and constancy of values, with some variation of ratio of gold and silver contents.

The Smuggler lode fills a fault fissure in augite andesite and the underlying andesite breccias. It has a thickness of 1 to 1.5 m. (3.2 to 4.9 ft.), sometimes up to 3 m., and is traceable a distance of 3 k. (2 miles). The vein filling consists of quartz, with a little calcite and barite. Quite uniformly interspersed throughout the quartzose gangue one finds pyrite, chalcopyrite, galena and zinc-blende, together with rich silver ores, especially proustite and polybasite, as well as native gold. For a distance of three-fifths of a mile not one spot was found unremunerative. The ores average 0.04% of silver and 0.0016% of gold. From north to south the gold content gradually increases, while the silver content decreases until at its south end the Smuggler is a true gold vein.

Silver-gold veins are also found in Custer County, Colorado, and have

[1] J. A. Church: 'The heat of the Comstock mines,' *Trans.* Am. Inst. of Min. Eng., 1879, p. 45.

[2] J. A. Porter: 'The Smuggler Union Mines, Telluride,' *Trans.* Am. Inst. of Min. Eng., 1896. Ch. Wells Purington: *Preliminary Rep.* on the Mining Industries of the Telluride Quadrangle, Col., 18th *Ann. Rep.* U. S. Geol. Surv., II, pp. 751-848.

been described by Emmons and Cross[1]. The ores contain besides free gold and auriferous tellurides, various rich silver ores, as well as sulphides of lead, zinc and iron. The gangue, however, differs from the deposits described in that barite predominates. These occurrences, too, are associated with recent volcanic eruptive centers.

Of these deposits the Bassick mine is the most interesting. The bedrock consists of gneisses intruded by granites, as well as by dikes of syenite and peridotite. This rock complex is covered by younger eruptive rocks, lavas, breccias and tuffs. The eruptive series begins with andesites. Next follow in succession diorites, dacites, rhyolites, younger andesites and trachytes. Finally, the andesitic agglomerations of Mount Bassick were accumulated,

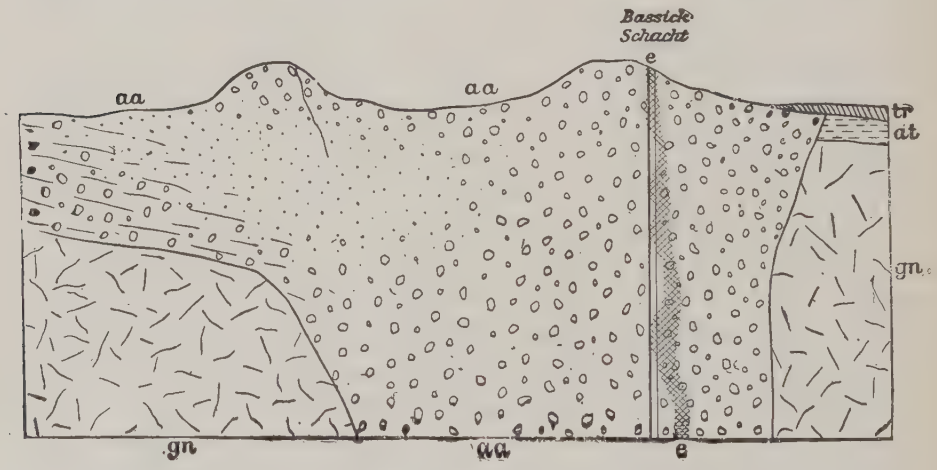


Fig. 178.—Section through the Bassick shaft. (S. F. Emmons.)
gn, gneiss; at, andesite tuff; tr, trachyte; aa, andesite agglomerate; e, ore shoot.

probably in consequence of vast volcanic explosions which broke up the older rocks. At some points there were subsequent eruptions of mica-dacite and glassy basalt. (See Fig. 178.)

A very remarkable ore deposit occurs in this Bassick agglomerate. Its form is hardly veinlike, but, mineralogically and genetically, it belongs to this class of the system. The deposit forms an upright stock of elliptical cross-section with diameters of 8 m. (25 ft.) and 30 m. (98 ft.) in the midst of andesite breccias. It has been followed to a depth of 1,200 ft. Not far from it a second deposit was found. In these 'pipes' the andesite

[1] Whitman Cross: 'Geology of Silver Cliff and the Rosita Hills, Colorado.' S. F. Emmons: 'The Mines of Custer County, Colorado,' 17th *Ann. Report* U. S. Geolog. Surv., II, 1896, pp. 269-470. *Idem.*: 'Some Mines of Rosita and Silver Cliff, Colorado,' *Trans.* of the Am. Inst. Min. Eng., 1897, Vol. XXVI, p. 773.

fragments, which vary from 1 cm. to a meter across, are surrounded by concentric layers of ore, varying between 1 cm. and 60 cm. in thickness. These encrusted fragments are impregnated with pyrite and are much more decomposed than those of the surrounding rock. The crusts of ore consist (from within outward) of (1) a blackish mixture of sulphides of zinc, antimony and lead with 0.2% silver and 0.005 to 0.01% gold; (2) a brighter thin layer, richer in lead, varying up to 0.7% of silver and 0.35% of gold; (3) a layer of crystalline zinc-blende 5 to 50 millimeters thick with 0.2 to 0.4% of silver and 0.5 to 0.16% of gold; sometimes also (4) a crust up to 2 centimeters thick of silver-bearing and gold-bearing copper pyrite; (5) a thin layer of pyrite. The free interspaces are filled with kaolin, but sometimes also contain quartz, gray copper, gold-telluride and silver-telluride, or secondary ores such as hydrosilicate of zinc and smithsonite.

The ore shoot is not sharply divided from the surrounding barren breccias, but in the latter there are fissures intersecting in such way that the ore column lies between them.

Emmons states that the vehicle for the metallic compounds was not vapor and gas which condensed on the fragments of the breccia, but solutions containing such gases, and he regards their rise as the last phase of the dying activity of this volcanic throat.[1] The John Jay mine near Jimtown, in Colorado, is worthy of mention in this place on account of the native tellurium found in masses weighing as much as 25 pounds.

Examples of the present group are also found among the gold deposits of Australia. Only one of them will be briefly described here, namely, the Hauraki goldfield, on the Coromandel Peninsula, on the north island of New Zealand, and reaching south as far as Waiorongomai. In this extensive area the Paleozoic rocks, and in part also late Cretaceous and Tertiary strata, according to Park, are intruded or covered by andesites, dacites and trachytes, as well as by their tuffs and breccias[2]. At many places the andesitic rocks are found altered to propylites, which in turn are intruded by younger underlying andesites. Numerous quartz veins traverse both the andesites and the propylites, but are mainly developed as workable gold lodes in the propylite only. Twelve groups of veins are distinguished in the area, among which the Thames group is richest and of the greatest scientific interest.

It lies in a tract about 2.7 km. (1.6 miles) wide, north of Hape creek. The veins striking northeast are intersected by two very large displace-

[1] Revised by S. F. Emmons.

[2] James Park: *Papers and Reports* relating to Minerals and Mining, Wellington, 1894, p. 52. K. Schmeisser: 'Australasien,' p. 92, also *Zeit. f. Prak. Geol.*, 1899, p. 366 *et seq.* 'The Hauraki Goldfield, New Zealand,' Waldemar Lindgren, *Engineering and Mining Journal*, Feb. 2, 1905.

ments, the Moanatairi and Collarbone faults, which divide the entire area into three terraces.

The thickness of the veins varies greatly. The largest, the Waiotahi, averages 3.5 meters wide, but is sometimes as much as 13 meters across. The veins are nearly all accompanied by lateral spurs or stringers. The gangue consists mostly of brittle, sugar-like quartz. The gold in it is finely divided, sometimes appearing in the form of wire and plates, and contains 30 to 40% of silver, giving it a whitish-yellow color. With it is found pyrite, and more rarely chalcopyrite, galena, manganese ores, zinc-blende, stibnite and gothite. A quartz vein of the Tararu mine contains much rhodonite, with finely divided gold. The largest lodes are generally poorest, and none have been worked to any great depth.

New Zealand in 1901 had a total production of 412,189 oz. of fine gold.

Instances of the silver-gold ore formation have lately become known also in the Dutch Indies, to wit: veins characterized by a large amount of selenium at the Redjang Lebong mine north-northeast of Benkoelen, in southern Sumatra. The lode, which is over 5 meters thick, and occurs in andesitic rocks, consists mainly of a dense-looking mass rich in silica.

The gold and auriferous silver (electrum), the latter predominating, occur disseminated in minute particles, invisible even under the magnifying glass. The composition of the crude bullion is as follows:

Gold and silver	91.52	per cent.
Se	4.35	"
Cu	1.82	"
Pb	1.65	"
Zn	0.48	"
Fe	0.14	"
	99.96	"

The average content of the 12,072 tons of ore produced up to 1900 was 45 gm. of gold and 385 gm. of silver per ton[1].

A similar deposit is worked at Lebong Soelit 7 to 8 k. (4.2 to 4.8 miles) farther west.

This type of vein is also represented in the Philippines[2].

18. *The Fluoritic Gold-Tellurium Veins.*

This group is closely related to the preceding, but is sharply characterized by the appearance of tellurides of gold and silver in a gangue of fluorspar and quartz. The ore minerals consist mainly of native gold, tellurides

[1] According to S. J. Truscott, cited in *Zeit. f. Prak. Geol.*, 1902, p. 225.

[2] F. W. Voit: 'Goldvorkommen auf den Philippinen,' *Berg u. Hütten. Zeit.*, Vol. LVII, 1898, p. 251.

and auriferous pyrites; to a slight degree of gray copper, galena, sphalerite, and stibnite.

The best known example is the goldfield of Cripple Creek[1], directly southwest of Pike's Peak, Colorado.

According to Cross a somewhat circular area of 4 to 5 k. (2.4 to 3 miles) in diameter, occurring in the midst of a very extensive tract of porphyritic granite, is covered by volcanic breccias and tuffs, whose material consists mainly of trachy-phonolite fragments, but in part also of fragments of the granite carried up from deep-seated masses. These volcanic accumulations are broken through in places by stock-like masses of trachy-phonolite and phonolite. The last-mentioned rock is exceedingly rare in the United States, being known only at one other place, viz., the Black Hills, So. Dakota.

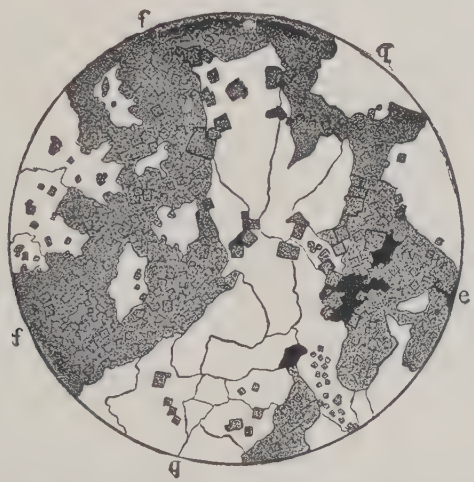


Fig. 179.—Thin section of a 'purple quartz' from Summit mine, Cripple Creek.
f, fluorspar; q, quartz with enclosed fluorspar crystals (outlines drawn by polarized light); e, iron ocher with free gold. (Enlarged fifty times.)

Finally the area is traversed by dikes of basic rocks, nepheline and feldspar basalts, which for the most part strike northeast and northwest.

These recent dikes are often accompanied along one wall by gold veins, while other veins also occur independently of the dikes, cutting not only the andesite, but also the underlying granite. The 'true fissure veins' are mere fissures, often an inch or less thick, and often entirely closed, but not only does this narrow fissure filling carry ore, but the strongly altered country rock on both sides is heavily impregnated with ore. These impreg-

[1] Whitman Cross: 'Geology of Cripple Creek;' and R. A. F. Penrose: 'Mining Industries of Cripple Creek,' 16th *Ann. Rep.* U. S. Geol. Surv., II, 1895. Also W. Lindgren and F. L. Ransome.

nation fissures contain gold tellurides, principally sylvanite and calaverite, rarely petzite, in less amount native gold, as well as auriferous pyrites, while in depth the ores contain gray copper, galena, sphalerite and stibnite. The gangue is quartz and fluorspar intimately coalesced, as shown in Fig. 179. The quartz is of a violet or reddish color, as it is thoroughly permeated with fluorspar; it is locally called 'purple quartz.' The metasomatic alteration of the country rock has been studied by W. Lindgren. The minerals, which are especially common as replacements of the orthoclase of the granite, include quartz, fluorspar, pyrite, sericite, as well as valencianite. The distribution of the tellurides or other ore minerals is very variable and uncertain. Very often ore shoots of very unequal size and shape are found in the same vein.

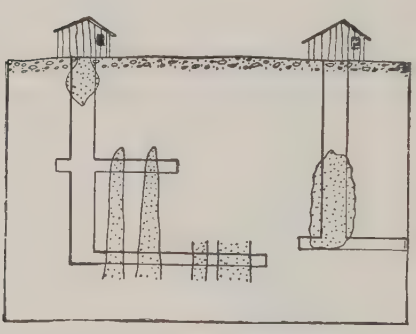


Fig. 180.—Columnar orebodies in a Cripple Creek vein. (R. A. F. Penrose.)

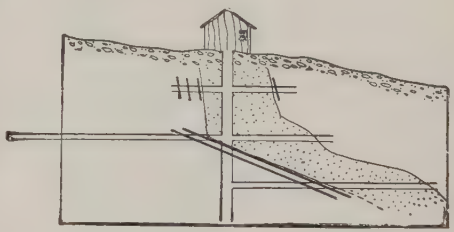


Fig. 181.—Orebody of a Cripple Creek vein. (R. A. F. Penrose.)

Ordinarily the ore shoots are approximately vertical columns varying from a few centimeters to several meters in thickness and up to 100 m. (328 ft.) long (see Fig. 180). The ore shoots sometimes occur directly under the grass roots, while more often their summits are only encountered in depth. In certain cases their location is at once seen to be dependent upon cross fissures, as shown in Fig. 181. These shoots sometimes yield very large amounts of gold.

A unique ore shoot of the Portland mine is called the "Anna Lee Chimney." A volcanic vent in basaltic rock has been worked to a depth of about 300 m. (984 ft.) This chimney, which is 4 to 9 m. across, is filled with rounded basalt fragments cemented by a calcareo-ferruginous material containing auriferous tellurides quite uniformly distributed.

Mention must also be made of the columnar masses of gypsum encountered in the breccias in the Deerhorn shaft. Rickard regards them as

deposits of thermal waters[1]. They may represent products of oxidizing sulphides on country rock and calcite.

The Cripple Creek district had long been known, but it was not until 1890 that gold ore was found in large quantities on what was afterward the Gold King mine in Poverty Gulch. Production began in 1891. According to Penrose it amounted to $5,543,967 from 1891 to 1894, inclusive. In 1898 the production was $13,507,349.

Deposits of gold with fluorspar also occur in Montana as described by Weed.[2] The Judith and Mocassin (Warm Springs) districts are situated in the Judith Mountains of Montana, which rise to a height of 6,386 ft. and extend over a distance of 29 km. (17 miles) between the arid grassy plains of the Yellowstone and those of the Missouri river. This mountain mass is an isolated uplift east of and independent of the Rocky Mountains. It consists of Paleozoic and Mesozoic limestones and shales, principally of Carboniferous age, domed by laccolitic intrusive masses. The gold deposits are found at the contact between limestones and syenite porphyries, which are regarded by the author as belonging to the trachyte group. The deposits consist of a contact breccia whose fragments are cemented by fluorspar, quartz, and a little calcite, with finely interspersed particles of tellurides, and the free gold formed by their alteration. The "purple quartz," an intimate mixture of fluorspar and quartz, recurs here.

The characteristic feature of the group of deposits last discussed, namely, the intimate blending of quartz and fluorspar, has been used by Penrose as the basis for a theory of the origin of these deposits. He imagines a reaction of soluble or gaseous fluorides with the calcium carbonate that resulted from the decomposition of calcareous silicates, or which is, as in the last example, supplied directly by the limestone. If the fluorine was introduced as hydro-fluoride of silicon, there might have been a simultaneous precipitation of fluorspar and quartz, such as we commonly have in the purple quartz. The original seat of the fluorine, as well as of the gold, Penrose imagines to have been heated rock masses found at great depths[3].

(η) Antimony Veins.

19. Antimony Quartz Veins.

This class of vein is closely allied to the antimonial gold quartz veins, and represents the extreme or gold-poor facies of the group. It is, how-

[1] T. A. Rickard: 'The Cripple Creek Volcano.' *Trans.* Am. Inst. Min. Eng., February, 1900.

[2] W. H. Weed and L. V. Pirsson: 'Geology and Mineral Resources of the Judith Mountains of Montana.' 18th *Ann. Rep.* U. S. Geolog. Survey, III, 1896–1897, pp. 445–614.

[3] See 'Telluride Veins of America,' Kemp, 'The Mineral Industry,' 1900.

ever, desirable, for practical reasons, to make a separate group of the deposits because they are worked for antimony, not for gold. Most of them carry but a very slight amount of gold, whose extraction is unprofitable by reason of existing metallurgic difficulties.

The prevailing gangue consists of quartz, with some calcspar. The ores contain stibnite and its products of decomposition, namely, stiblite, antimony-ochre, valentinite and senarmontite, more rarely also antimony blende (pyrostibnite) and sometimes pyrite, bournonite, berthierite, galena, zinc-blende, steinmannite, zinckenite, and cinnabar ochre, rarely native gold. Ordinarily the stibnite is interspersed in the gangue, in rare cases it occurs in compact masses, forming almost all the vein filling, or it is concentrated into ore shoots, while the rest of the vein is lean.

A description of examples will better explain the characteristics of this type.

At Böhmsdorf and Wolfsgalgen, near Schleiz, the Paleozoic schists are traversed by veins of quartz carrying stibnite, with minor amounts of zinc-blende, plumose stibnite, pyrophyllite and ironspar. The veins have sometimes been extensively mined, as at the Halber Mond mine at Bohmsdorf in the fifties of the 19th century.

Among the antimony deposits of Bohemia special mention must be made of that of Pricov, near Selcan, 15 kilometers west of Wotitz, in central Bohemia. At that locality, according to A. Hofmann, a great number of kersantite dikes occurring in granite, are accompanied by veins of hornstone rich in stibnite. The veins were worked for antimony alone for many years, but were abandoned in 1897. The ores held no free gold, and the stibnite contained only traces of that metal. For a depth of 18 m. (59 ft.) below the croppings, the stibnite was changed to antimony ochre (stibiconite). The largest vein, which has a thickness of as much as 20 meters, and forms the rocky crest of the Deschna mountain, does not contain stibnite throughout its entire mass. It is only where the hornstone assumes a light gray color that it is found, when examined under the microscope, to be completely filled with innumerable handsome crystals of ore, and also to carry larger segregations of it. Thus far only the Emil lode, 10 to 50 centimeters thick, has been worked.

Entirely similar, but less extensive, lodes are found at Punnau, near Marienbad. They occur in mica schist and amphibolite near the great granite massive of that locality[1].

In Hungary antimony ores are still extracted from the veins of the Rechnitz Mountains, of the Eisenburger Comitat. Some of the veins have been

[1] J. Schwarz: 'Das Punnauer Antimonbergwerk bei Michaelsberg in Böhmen.' *Oesterr. Z. f. B. u. H.*, 1881, pp. 595–608.

followed for a distance of 3 km. (2 miles), cutting crystalline schists. According to A. Schmidt[1], the veins are especially rich when the country rock is a chloritic or graphitic schist. The vein filling consists of quartz, calcspar and stibnite, with stibiconite and pyrite. The masses of antimony ore proper attain a thickness of 2 to 50 centimeters. The graphitic schists alongside of the lodes, for a distance of 3 to 4 meters from the vein walls, are so richly impregnated with stibnite, together with pyrite and cinnabar, that they also pay working. The pyrite of this ore contains about 0.0021% of gold.

Other veins of stibnite, with a gangue of quartz and carbonates, with small amounts of jamesonite, berthierite, blende and auriferous pyrites, were worked between Aranyidka and Rosenau, in upper Hungary[2].

A noteworthy deposit of antimony occurs at Pereta, south Tuscany. According to Coquand[3] and Toso[4] it consists of a mass of crushed white quartz, whose north end is intercalated in Eocene limy shales, while to the south it cuts Miocene limestones. To the north of the outcrop exhalations of hydrogen sulphide (putizze) occur. The stibnite occurs in the quartz in the form of stringers and pockets, occasionally of large size. Sulphur occurs with it and in the northern part of the deposit considerable amounts have been extracted. In these workings the sulphur-bearing quartz is occasionally seen to be coated with a crust of stibnite, which in turn is studded with small crystals and aggregates of sulphur. Eocene limestones, at the contact with the deposit, are traversed by quartz stringers and largely altered to gypsum or to alum rock.

Stibnite associated with cinnabar is found at other places in Tuscany, notably San Martino, in the Monte Amiata district[5].

In recent years the veins of the northern part of the island of Corsica have become important producers. The veins occur in sericite schist, the gangue materials being quartz, calcite, blende with antimonite and more rarely pyrite, cinnabar and bournonite[6].

In Portugal rich veins of stibnite worked until recently occur 40 km. (24 miles) east of Porto, in the Moinho da Igreja, and San Pedro da Cova, on the Rio Ferreira. They traverse Paleozoic schists.

[1] A. Schmidt: 'Ueber einige Minerale der Umgebung von Schlaining.' Groth's *Z. f. Kryst. u. Min.*, 1898. Vol. XXIX, part 3, p. 194.

[2] G. Faller: 'Reisenotizen.' *Jahrb.* d. k. k. Montanlehranst., 1867, p. 132.

[3] H. Coquand: 'Solfatares, Alumières, etc., de la Toscane.' *Bull.* Soc. Géol. de France, VI, 1829.

[4] P. Toso: *Rivista del Serv. Min.*, 1899, p. 144.

[5] B. Lotti: 'Zinnober- und Antimonlagerstätten Toscanas.' *Zeit. f. Prak. Geol.*, 1901, pp. 43–46.

[6] M. Nentien: 'Etude sur les gîtes minéraux de la Corse.' *Ann. des Mines*, Vol. XII, 1897, pp. 231–296.

The central plateau of France is very rich in antimony. According to Fuchs and De Launay[1] the most important lodes are found in various rocks, viz.:

Mica schist in the worked-out mines of Nades in the Bourbonnais; in granite at Bresnay; on the contact between granite and gneiss at Montignat (Allier) at Villerange, in the Culm graywackes, south of Saint-Yrieux (Haute-Vienne). Great numbers occur in mica schist and amphibole schist, at Freycenet, and elsewhere in the cantons of Puy-de-Dôme, Cantal, and Haute Loire, where they are still extensively mined for antimony ore. Quartz is the main gangue, accompanied at Malbose (Ardèche) by a little calcite and barite.

The stibnite is accompanied by arsenopyrite, occurring in small quartz veinlets in Carboniferous aplite dikes, forming veritable stockworks at Montignat (Allier)[2].

Similar deposits are known in Australia, viz., on Macleay river, South Australia, on Donovan's creek and on the Upper Yarra, near Sunburg, Victoria, and in the Hillgrove district, New South Wales.

Mexico contains important antimonial veins, traversing quartzites and limestones at La Sonora. Deposits in Asia Minor are described by K. E. Weiss[3].

Much discussion, especially upon the mineralogic associations, has been aroused by the stibnite veins of Japan. According to K. Yamada[4] they are especially abundant on the island of Shikoku; they are not thick, and occur mostly in schists and other Paleozoic rocks. Quartz is usually the only gangue, the stibnite being sometimes accompanied by pyrite.

The largest and most famous antimony mine of Japan is that of Itshinokawa on Shikoku, which furnishes large stibnite crystals.

The country rock is a sericite schist, which is impregnated with pyrite near the veins. Four east-west lodes are known, three of which dip about 80° south, the other but 25° in the same direction, this being the one containing the large crystals up to 0.5 meter long. The gangue is quartz with a little calcspar; the vein filling is banded with druses containing the large crystals. With one exception, the Nakase mine, the antimony ores do not carry gold. The Itshinokawa district produced 799 tons of antimony sulphide and 83.8 tons of refined antimony in 1897[5].

Great quantities of antimony ore have also been from time to time ex-

[1] Fuchs and De Launay: 'Traité des Gîtes Minéraux.' Vol. II, 1893, pp. 193–199; with full bibliography.

[2] L. De Launay: *Compte-Rendu* du VIII Géol. Congrès Inter., 1900.

[3] K. E. Weiss: 'Lagerstätten im West. Anatolien,' *Zeit f. Prak. Geol.*, 1901, part 7.

[4] Letter to the author.

[5] 'Les Mines des Japan,' Paris Exposn., 1900, p. 10.

ported from Borneo. The ore comes from veins at Tambusan and Tagui, in the Sarawak district, in the northern part of the island. They occur in limestone and slate and carry stibnite, oxidized antimony ores, and as a rarity native antimony, in a quartzose gangue.

While in most cases the antimony veins may be regarded as extreme members of the antimonial gold quartz veins, in which the gold content is nil, and vice versa, there are, on the other hand, examples of antimony veins which may be regarded as extreme developments of the class of rich silver veins. An example of this kind was mined until the sixties at Mobendorf, Saxony, seven miles northwest of Freiberg[1], which Freiesleben has designated as the Mobendorf type. According to H. Müller[2], these veins occur in gneiss, have a steep dip and but rarely exceed 5 cm. in thickness. Their filling consists of stibnite, with some berthierite, bournonite, striated kaolin, steinmannite (antimonial galena), zincite, kermesite, stibiconite, pyrite, quartz and some brownspar. A few kilometers farther east-southeast at Bräunsdorf the same ores are found intimately associated with rich silver ores in the rich silver quartz veins.

(δ) Cobalt-Nickel and Bismuth Veins.

Two classes of veins, quite different from each other, are included under this heading, viz.:

A. Veins composed essentially of cobalt-nickel and bismuth sulphides.

B. Veins consisting of nickel-magnesia hydrosilicates. The first group is itself subdivided into a class characterized by a gangue composed mainly of a carbonspar gangue, with pure cobalt-nickel ores, and a second class characterized by a gangue of quartz, and other siliceous minerals in which carbonates are subordinate, containing bismuth ores, besides cobalt-nickel ores.

Accordingly the various groups may be designated as follows:

1. Cobalt-nickel deposits with carbonate gangue.
2. Quartzose cobalt-nickel-bismuth deposits.
3. Hydrosilicate nickel deposits.

Further differences between these three groups will be given in the description of various examples.

[1] J. C. Freiesleben: 'Magazin für Oryktographie von Sachsen.' 1. Appendix, p. 77 2. Appendix, p. 179.

[2] H. Müller: 'Erzlagerstätten bei Freiberg.' Cotta's Gangstudien, I, 1850, p. 104.

20. Cobalt-Nickel Veins with Carbonate Gangue.

This type is most pronounced in the cobalt veins of Dobschau, Hungary, which represent an extreme facies of the spathic iron-ore veins.

According to Voit,[1] chloritic-talcose and quartzose Paleozoic slates are intruded by a sheet of diorite, which follows the contact with a stock of garnetiferous serpentine. The diorite is badly altered and shows transitions from a hornblende diorite to a hornblende granitite. The basic contact facies next to the clay slate has been altered to a chloritic schist rich in epidote. The cobalt veins on the south flank of the Langenberg, four miles south of Zemberg, cut the diorite close to its contact with the underlying chloritic schists. Three lodes composed of veins with steep southerly dip are recognized, each one dividing into fanlike stringers above, while downward they disappear, or at any rate grow barren, at a depth of 180 to 200 m. (590 to 655 ft.) The fissures are not over 3 m. (10 ft.) thick, and consist mainly of siderite, calcite, ankerite and some quartz. In the southern veins tourmaline needles also occur, usually in the quartz, more rarely in the siderite. Many fragments of decomposed country rock also occur in the vein. The ore minerals occur as in pockets, parallel layers, and large compact bodies, irregularly scattered through the vein. The common ore is a compact, very finely crystalline mixture of smaltite (cobalt pyrite) and Rammelsbergite ($NiAs_2$). The richer ores yield 8 to 10% of cobalt and about 17% of nickel, others only 4% of cobalt, but hold 22% of nickel. This ore is usually fissured, the fractures showing slickensides, whose glassy surface is coated with carbonaceous material. Rich orebodies, consisting of tetrahedrite, sometimes occur in the upper parts of the vein. Chalcopyrite, bornite, arsenopyrite, lollingite ($FeAs_2$) and niccolite are rarely observed. Secondary ores, erythrine, malachite, etc., also occur.

The cobalt veins broaden upwards into trumpet-shaped expansions of coarsely crystalline siderite as much as 100 feet thick, which are exposed by great open-cuts, at Langenberg, Bingarten and Massörtern. These deposits completely fill irregular depressions on the surface of the diorite, and are in turn overlain by Carboniferous sandstones, slates and limestones carrying segments of crinoid stems and other fossils. These deposits seem to be connected with the lodes, for the siderite contains scattered nests, or even distinct layers in its lower layers, of nickel ores, together with some tetrahedrite, chalcopyrite, arsenopyrite and brown hematite. The solutions rising in the ore-bearing fissures seem to have metasomatically replaced part of the Carboniferous limestone overlying the diorite.

[1] F. W. Voit: 'Geognost. Schild. d. Lagerst.-Verh. von Dobschau in Ungarn.' *Jahrb.* d. k. k. geol. Reichsanst., 1900, Vol. L, part 4.

Besides the cobalt-nickel veins, the region also contains veins of carbonate spars free from cobaltiferous ores, especially an 8-meter (25-ft.) vein at the diorite contact, worked for siderite, and which is notable because it is accompanied throughout its entire course by a quartz vein containing chrome-mica.

The iron deposits of Dobschau still yield an annual production of about 35,000 tons, but the cobalt veins have been abandoned for some years. The total production reported from 1840 to 1880 was 26,000 tons of cobalt-nickel ore.

The cobalt veins of Thuringia differ from those of the Dobschau, just described, since they contain barite. They have been worked for many years, especially at Schweina, near Liebenstein.

According to Fr. Beyschlag[1] the veins are fault fissures with a steep southwest dip and a maximum thickness of ¾ meter. The beds of the Zechstein formation, which dip southwest at 4½°, together with the copper-bearing layer of this formation, show a displacement along the veins of 3 to 8 m. (22 to 25 feet) and as much as 30 feet in exceptional cases. The vein filling consists of barite, calcspar, fragments of the country rock and smaltite, asbolite and erythrite. These vein fissures exert a remarkable influence on the bed of 'copper schist.' This Kupferschiefer is lean in this district, carrying only 1.4% of copper, and no silver, but, where it is traversed by the cobalt veins, it is enriched and holds 3 to 4% copper. At the same time the amount of copper in the uppermost layer of the Zechstein conglomerate, which immediately underlies the copper schist, rises from 3 to 10%. In particular the Beyschlag vein, discovered in 1901, proved very rich in ore.

Smaltite, niccolite, asbolite, rammelsbergite, erythrite and nickel green (zaratite?) in subordinate amount, it is true, together with chalcopyrite and tetrahedrite, were also found in the copper veins of Kamsdorf and at the Rothen Berge at Saalfeld (see p. 227). Barite and various carbonates, especially siderite, are the prevailing gangues.

The fault fissures known as 'rucken' in the Mansfeld copper district also contain occasional nickelite, together with chalcocite, bornite, chalcopyrite, pyrite, calcspar, brownspar, ironspar, barite and rarely also rammelsbergite[2].

Similar lodes in Paleozoic schists were formerly worked at Lobenstein, in the principality of Reuss.

Other veins occur at Nanzenbach, near Dillenburg, in Nassau, in paleo-

[1] F. Beyschlag: 'Kobaltgänge von Schweina.' *Zeit. f. Prak. Geol.*, 1898, pp. 1–4.

[2] Baeumler: 'Ueber das Vorkommen von Nickelerzen im Mansfeldischen Kupferschiefergebirge.' *Zeits. d. D. G. G.*, Vol. IX, 1857, pp. 25–50.

picrite and volcanic tuffs[1]. They carry siderite, ankerite and quartz as a gangue, containing nickel pyrite and bismuth glance, nickeliferous iron pyrite, copper pyrite, and some ores of secondary formation.

21. Quartz-Cobalt Veins.

(Quartz-Cobalt-Bismuth Deposits.)

One of the best known examples of this type is the cobalt district of Schneeberg, in Saxony, a mountainous region 1,300 to 1,600 feet (400 to 500 m.) above the sea, in which clay slates of the Phyllite formation of the Erzgebirge adjoin Cambrian mica schists, and are intruded by the great granite stocks of the western Erzgebirge. Most of the veins outcrop in the interval between the granite masses of the great Eivenstock, Kirchberg and Schlema. This entire mass of schistose rocks has been altered by contact metamorphism, but small remnants show the original nature of the rocks. The contact zones are particularly marked, because the top of the granitic intrusive masses almost everywhere dips gently under the schists, being partly concealed by them, as may be seen by an examination of Dalmer's sections[2], Fig. 182 and 183. The country rock is partly normal phyllite and clay slate, but mainly metamorphic rocks resulting from the contact action of the granite, particularly carpolite, hornfels and andelusite-mica rocks, as well as striped augite-hornblende schist. In addition to this the Eibenstock tourmaline-granite and the porphyritic granite of Oberschlema are also present.

Besides quartz-cobalt veins the Schneeberg district contains quite a variety of vein types, which, according to the monograph of Müller[3] and later communications by H. Tröger, are divided into two main groups, an older and a younger.

The older veins include tin deposits, the quartz-copper veins and pyritic-lead veins, as well as barren quartz veins, deposits which have in part been already mentioned in their proper place in this work. The younger vein group is, on the contrary, made up of quartz-cobalt veins, rich cobalt-silver veins and lastly the iron ore deposits.

The class of quartz-cobalt veins, also called cobalt-bismuth veins on account of their high percentage of bismuth, are decidedly the most economi-

[1] v. Koenen in *Zeits. d. D. G. G.*, 1863, Vol. XV, p. 14. E. Frohwein: 'Beschreibung des Bergrevieres Dillenburg.' Bonn, 1885. W. Riemann: 'Der Bergbau und Hüttenbetrieb der Lahn-, Dill- und benachbarten Reviere.' Wetzlar, 1894, p. 37.

[2] K. Dalmer, E. Köhler and H. Müller: 'Section Schneeberg der geol. Spezialkarte von Sachsen nebst Erläuterungen.' 1883.

[3] H. Müller: 'Der Erzdistrict von Schneeberg im Erzgebirge.' B. v. Cotta's Gangstudien, 3d Ser., 1860, pp. 1–223; with bibliography.

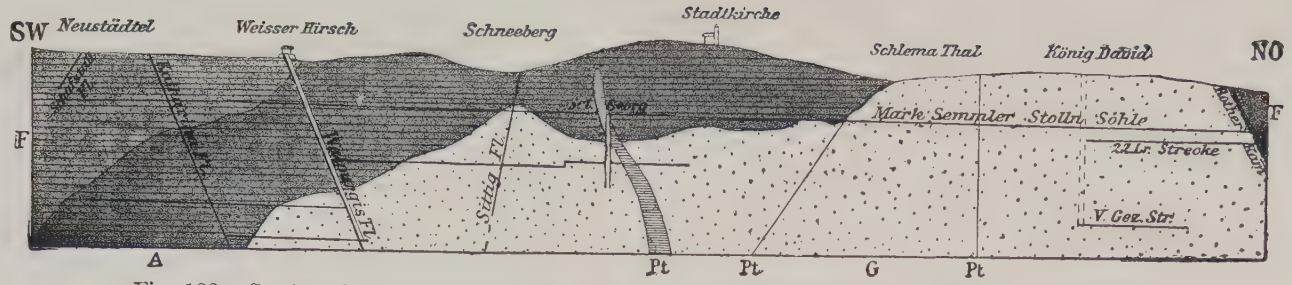


Fig. 182.—Section through the northern part of the Schneeberg cobalt district. (K Dalmer.)
F, carpolite; A, andalusite-mica rock; G, granite of Schlema; Pt, porphyrite.

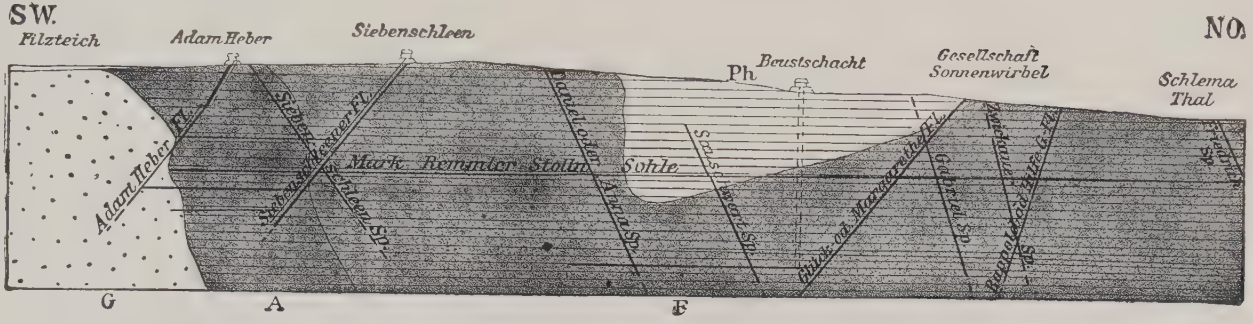


Fig. 183.—Section through the southern part of the Schneeberg cobalt district. (K. Dalmer.)
Explanation as in Fig. 182. Ph, phyllite.

cally important deposits of the entire district. At Schneeberg, the veins are so crowded together in an area but 3 miles long and 2 miles wide, that Müller called the whole area a stockwork. Over 150 lodes have been exposed in mining. The veins occur in two bands, intersecting at an acute angle. One of them strikes northwest to north-south, the other west-northwest to northwest. In both systems the dip is steep, mostly 60° to 80°, partly northeast, partly southwest. The thickness varies between 2 centimeters and 3 meters, but is mostly less than 0.5 meter. Many show a decided tendency to stringers, and the junctions of such stringers are apt to be especially rich.

The fissure filling consists mainly of disintegrated, decomposed and partly mineralized and silicified country rock. The gangue minerals include quartz, mostly finely granular, crystalline and transparent, a gray and red hornstone, and some chalcedony and jasper. Carbonates such as calcspar, brownspar, rhodochrosite colored by cobalt, etc., are less prominent, and barite and fluorspar are very rare. The carbonate minerals are more common in vugs than in the solid vein filling. Calcspar occurs in a great variety of crystalline forms, especially prisms with one or two flat rhombohedrons and disc-shaped, perfectly flat rhombohedron combinations, the so-called paper druses, for which Schneeberg is famous. The most frequent ore minerals include smaltite in two varieties, one tin-white, the other a gray granular or crystalline variety rich in iron, chelentite (bismuth-cobalt-pyrite), asbolite, and erythrite, which also occur in large stalactites of recent formation. The nickel ores include rammelsbergite and smaltite, native bismuth, often in magnificent aggregates of netted crystals, bismuth ochre, and finally pyrite. Among the rarer ingredients are bismutite, bismuthinite, eulytite, cobaltspar, pucherite, roselite, native silver, argentite, proustite, pyrargyrite, polybasite, and other rich silver ores, marcasite, arsenious pyrite, native arsenic, uranium pitchblende (now famous as the source of radium), autunite, and the rarer uranium ores, trögerite, walpurgite, zeunerite, uranospinite, uransosphaerite, occur in the Walpurgis veins. Copper ores, zinc-blende, galena, etc., occasionally occur.

Among the gangues mentioned above, the quartz and the other siliceous minerals did not constitute the original and characteristic accompaniments of the cobalt and bismuth ores of Schneeberg. The carbonates, especially brownspar and calcspar, were formerly far more abundant, probably in association with barite, but were in part subsequently removed and replaced by silica. This is shown by the pseudomorphs for which Schneeberg is well known, consisting of quartz and hornstone, rarely also of chalcedony, after calcspar and sometimes after barite. The first named often contain a core of undecomposed calcspar. The latter are apt to represent large-celled

aggregates of intersecting plates composed of a multitude of small quartz crystals with empty interspaces, showing that the replacement is not yet completed. Pseudomorphs of this kind have been found, in a half-finished condition, as it were, being soft and crushable with the finger, but hardening into a crystalline quartz mass on exposure to the air[1].

Certain cobalt veins of this locality are still composed almost wholly of carbonate minerals to a considerable depth, contrary to the general rule; they thus form a transition between the quartzose, Schneeberg type and carbonspathic cobalt-nickel deposits. Thus large parts of the Adam Heber vein consist of nothing but brownspar and some calcspar, and it is seen that the ores are here developed in different proportions. Chloanthite and niccolite predominate and carry 6 to 8% or even 20% of silver. In this gangue uraninite (pitchblende) also occurs, while in those portions where this lode carries its normal siliceous gangue, smaltite and native bismuth are also present.

The gossan of the Schneeberg cobalt-bismuth veins is unusually deep, extending down for 425 to 550 feet, and seldom as little as 250 feet. In the gossan, bismuth ochre and the other oxidized ores occur, sometimes in rich workable orebodies close to the sod. The vein filling is in most cases irregularly massive, more rarely banded.

H. Müller has shown that in general the cobalt-nickel ores and bismuth ores are found where quartz and hornstone predominate over the carbonates; that the rich silver ores occur mainly associated with calcspar; that nickel ores occur especially in the initial and terminal parts of the cobalt orebodies and that uraninite (pitchblende) is as a rule associated with chalcopyrite and galenite.

In late years it has been proved that as a rule the Schneeberg veins become barren where the fissures pass into the underlying granite. Only in exceptional cases, as in the Katharina vein on Weisser Hirsch, do the rich cobalt ores extend for any considerable distance downward into the granite. The vein just named shows a remarkable impregnation of the granite with pitchblende. It was observed in the foot-wall country rock on the 850 foot cross-cut, although the vein itself had, above the level, ceased to show the uranium ores mined near the surface. In this very peculiarly limited and slight downward extension of their orebodies, the cobalt veins resemble the tin lodes. Like them they are genetically connected with the intrusive granite massives and occur only above them or in their uppermost parts. No workable orebodies have thus far been found in the Schneeberg

[1] This structure is common at the Drumlummon (Montana), De Lamar (Idaho) and other American mines. It is forming at Boulder Hot Springs (Montana), and has been observed at Guanajuato, Mexico, and Leon, Nicaragua, by W. H. W.

mines deeper than 460 to 480 m. (1,500 to 1,600 ft.) The cobalt-silver veins of the Schneeberg cobalt district merit a few words. Only a few veins of this type are known, but they were very rich in silver and the development of the district and the building of the town resulted from their discovery and wealth. They show a great resemblance in their whole development to those of Annaberg, previously described. The large amount of barite in the gangue led Müller to designate them as barytic cobalt-silver deposits.

Very frequently the ores are a secondary or later deposit in an older primary filling of veins of the group just discussed. The later filling, itself, however, sometimes has been reopened and filled with iron-and-manganese ores. The vein filling, therefore, consists of quite heterogeneous constituents. The gangue consists of coarsely foliated barite, less frequently fluorspar, brownspar, calcspar, and quartz; the ore minerals are cobalt, nickel, and bismuth sulphides, slightly argentiferous galena, the rich silver sulphides and polysulphides, as well as iron and manganese ores.

A famous example is the Sanct Georg or Michael vein, mined to a depth of 760 meters (2,500 ft.).

The iron-manganese veins of Schneeberg are also important, since they fault the cobalt veins. One of the most important of these fault veins is the so-called Rothe Kamm, which, striking north-northwest, cuts off sharply the granite bodies of Oberschlema and Auerhammer, and may be traced for a distance of 5 kilometers. Lastly, this remarkable district contains the so-called Schwebende lodes, zones of strongly fractured and altered rock, running parallel to the stratification of the slates, and impregnated with some quartz, brownspar, galenite, arsenopyrite, pyrite, chalcopyrite and brown hematite. At intersections with transverse veins they became a little richer and have at several points been worked for silver. Mining at Schneeberg was originally confined to its very rich silver veins, but this gradually declined and mining only recovered when the employment of the cobalt for the manufacture of dyes gave a value to this formerly neglected metal. In 1540 the first bluing works were established at Platten in the Erzgebirge. The mining industry was stimulated anew by the increasing employment of nickel and bismuth in the metal industry; among other things by the invention of German silver by E. A. Geitner in Schneeberg in the beginning of the twenties of the 19th century.

The cobalt mines of Schneeberg are now owned by the Royal Treasury of Saxony and by the Sächsiche Privat-Blaufarbenwerks-Verein. The output in 1898 was only 307.7 tons of argentiferous cobalt-nickel and bismuth ores.

Remarkable cobalt veins exist at Balmoral, east of Pretoria, in the

Transvaal. They consist of hornstone with actinolite, smaltite and erythrite, and occur in the schists of the Cape formation[1].

Surprisingly rich veins of cobalt-nickel arsenides, very rich in native silver, were discovered in slate at Haileybury, in Ontario, Canada, in 1903, while a railway cutting was being excavated.[2]

22. Veins of Hydrosilicate Nickel Ores.

This type of nickel vein occurs only within serpentine. The veins consist of garnierite, a mixture of hydrated nickel silicate in greatly varying proportions, usually carrying 6 to 12% of nickel, though perfectly pure portions are richer; of numeaite, distinguished from the preceding by its darker color and greasy feel; genthite, as the more highly nickeliferous varieties of garnierite are called; and pimelite, the aluminous variety, as well as magnesite, limonite, allophane, cerolite, chrysoprase, chalcedony and quartz. Ordinarily there are no large veins, but merely a network of small stringers in the serpentine.

The most important deposits of this class are those of New Caledonia[3], a long island extending from northwest to southeast, midway on the route from the Australian continent to the Fiji Islands. The veins occur especially in the environs of Numéa, Dombéa, Thio, Mont Mou, Mouéo and Gomen.

The most important deposits of this class are those of New Caledonia[3], pentine massives with which the nickel ore deposits are associated form rounded, dome-shaped elevations in sharp contrast with the jagged crests of the Archean rocks, and the gently undulating lands formed of the Triassic, Jurassic and Cretaceous beds. The veins and stringers of garnierite and numeaite are common at the boundary between the serpentine and the variegated clays resulting from the decomposition of the serpentine. These clays contain no nickel, but carry iron cobalt and chrome ores. The nickel-bearing serpentine stocks cover about 6,000 square kilometers, or one-third of the entire island. The nickel deposits were discovered in 1863 by J. Garnier, and described in 1867. The exportation amounted to 140,000 tons in 1901, the ores carrying 4 to 4.5% of metallic nickel. In the ores exported in former years the nickel content varied between 4.5 and 10%.

[1] G. A. F. Molengraaf: 'Geol. de la Rep. Sud Afrikaine,' 1901, p. 60.

[2] W. G. Miller: 'Cobalt-Nickel Arsenides and Silver,' *Report* Ontario Bureau of Mines, 1904, part I, pp. 96–103.

[3] J. Garnier: *Ann. des Mines*, 1867. A. Bernard: 'L'Archipel de la Nouvelle-Calédonie.' Paris, 1895. p. 458. Fr. Danvers Power: *Proc.* of the Inst. of Min. and Met., London, 1900. Vol. VIII, p. 44. Abstract in *Zeit. f. Prak. Geol.*, 1901, p. 24 *et seq.* G. Henriksen: 'Om Nikkelmalmen i Ny Caledonien.' Teknisk Tidskrift, February, 1902.

The production from 1896 to 1900 was 374,000 tons of nickel ore. The production of cobaltiferous manganese ores with 3 to 5% of cobalt oxide, found on the east coast of the island, is rapidly increasing.

J. B. Jaquet reports the occurrence of asbolite deposits in clay and serpentine, particularly at the boundary of these rocks[1] at Port Maquarie, in New South Wales.

An American district lies near the town of Riddles, Oregon. The rock in which the nickel veins occur nas not been serpentinized to so great a degree as in New Caledonia. At Mount Piney, three miles west of Riddle, the rock is a remarkably fresh harzburgite, consisting of about two-thirds of olivine, with one-third bronzite, chromium and magnetite. According to J. S. Diller[2] the rock contains, among other things, 0.76% Cr_2O_3 and 0.1 NiO, while the olivine, though not absolutely free from bronzite and chromite, contains 0.79% Cr_2O_3 and 0.6% NiO. Even the unaltered olivine rock is traversed by serpentine veins. These contain a magnesia-nickel silicate resembling garnierite, but distinguished from it under the name of genthite, on account of its greater nickel content (12 to 29% NiO). This segregated at first in finely interspersed patches and small veins, accompanied by quartz and iron oxide. Little by little the rock is traversed by so dense a network of such veinlets that it assumes a coarsely netted or brecciated structure. Finally larger accumulations of genthite are formed, which, always associated with quartz and chalcedony, fill the fissures, sometimes with distinctly bedded arrangement. The change in volume of the original olivine rock by the absorption of water during serpentinization favors the formation of stringers, which is the dominant characteristic in the development of these lodes. Another nickel locality of great scientific interest is Webster, North Carolina.

In recent years nickel has been extensively mined at Frankenstein[3], in Prussian Silesia. The deposits occur in the Gläsendorf-Kosemitz serpentine range, whose rock, besides remnants of olivine, contains magnetite, chromite and abundantly disseminated prisms of tremolite. This serpentine is cut by numerous long fissures, mainly filled with a brownish red friction product, usually distinctly brecciated, consisting of serpentine and

[1] *Australian Mining Standard*, February 17, 1898.

[2] F. W. Clarke: 'Some Nickel Ores.' *Amer. Journ. of Sc.*, Vol. XXXV, p. 483. H. B. von Foullon: 'Ueber einige Nickelvorkommen.' *Jahrb.* d. k. k. geol. Reichsanst., 1892, Vol. XLIII, part 2. W. L. Austin: *Zeit. f. Prak. Geol.*, 1896, p. 203.

[3] J. L. Meinecke: 'Ueber den Chrysopras und die denselben begleitenden Fossilien in Schlesien.' 1805. J. Roth: *Erläut.* zu der geol. Karte vom niederschlesischen Gebirge, 1867. B. Kossmann: 'Die Nickelerze von Frankenstein in Schlesien.' *Berg u. Hutten. Zeit.*, 1890, pp. 111–113. Also Essener Glückauf, 1893, No. 54. H. B. von Foullon: *op. cit.*, p. 257 *et seq.*

talc and ferruginous clay. At the selvage the filling sometimes assumes a thinly foliated structure as a consequence of great pressure. These veins, which are associated with imperfectly defined zones of disintegration, are themselves traversed by numerous stringers, often either mere plates several cm. thick, or irregular veins, of pimelite, garnierite, cerolite, sepiolite, schuchardtite (an aluminous magnesium hydrosilicate with 8 to 17% nickel), quartz, hornstone, white opal and chrysoprase. Brown red masses with scattered spots or nests of pimelite, locally called nodular ores, occur irregularly scattered through the broad lodes and sometimes form large stocks. Among the cobalt ores earthy erythrite may be mentioned as a rarity. At the present time the nickel deposits have been mined to a depth of 56 m. (183 ft.) Down to 52 m. (170 ft.) the mine was dry. Chrysoprase, the gem popular in the 18th century, was extracted as early as 1740, but nickel mining is of recent date. In 1901 9,500 tons of ore were extracted and 114.3 tons of nickel were produced. There was a considerable increase of production in 1902. Magnesite is also mined, especially from the Buchberg, south of Frankenstein.

The analagous deposits at Revda (or Rewdinsk), west-southwest of Ekaterinburg, in the Ural, are more siliceous than those just described. At this locality[1] a band of antigorite-serpentine is intercalated in a zone of crystalline schists and crystalline limestones. The serpentine has, according to H. B. von Foullon, been derived from a feebly nickeliferous pyroxene rock. In the serpentine which has thus become nickeliferous, a concentration of the nickel takes place on further decomposition, considerable amounts of silicic acid being segregated, together with hydrated nickel-magnesia silicates. Hence the ores consist in a large part of small nodules and fragments of nickel-magnesia silicates cemented by quartz into a breccia. The reopening of fissures and the continued deposition of silicic acid has, moreover, formed breccias consisting of quartzose nickel ore fragments, with a cement of pure quartz. The final result of the decomposition of the serpentine is a ferruginous residue containing pockets of nickel silicate, sometimes of asbolite. Sometimes these new formations have taken place in extensive fissures, which may be due to mountain-building forces. Thus H. Müller described from Revda a vertical vein over 2 meters thick in serpentine and adjoining chloritic schist. The filling consists mainly of corroded quartz and chrysoprase. In this lumps of nickel up to the size of an apple were found in cavities associated with fatty clays.

[1] H. Müller: 'Ueber die Nickelerzlagerstätten von Rewdinsk.' *Berg u. Hutten. Zeit.*, 1866, p. 65. H. B. von Foullon: *op. cit.*, p. 234 *et seq.* A. Karpinski: 'Ueber die Lagerstätten der Nickelerze im Ural' (in Russian). *Gorni Journal*, 1891, No. 10.

Quicksilver Veins.

The principal ore of this class is cinnabar. Accompanying this there are found, mostly in small quantities, native quicksilver, metacinnabarite and calomel. Associated pyrite always occurs, with occasional particles of marcasite and copper pyrite, more rarely stibnite, arsenopyrite, realgar and other sulphides. The principal gangues are quartz, chalcedony, opal, calcspar and dolomite, very frequently also various forms of bitumen. Barite, fluorspar and gypsum are less frequent.

Besides true veins the quicksilver ores form impregnations in the adjoining disintegrated and much fissured rocks, or in originally porous rocks and may form stockwork orebodies.

Since the conditions at Sulphur Bank and Steamboat Springs have become known (see later), no one can doubt that quicksilver deposits are formed in the hydrothermal way. The quicksilver seems to have been in solution as $HgS+4Na_2S$, a double salt whose formation is readily possible in the presence of dissolved carbonates and sulphohydrates of the alkalies at a high temperature. The bituminous substances, which are almost always alongside of the cinnabar in Nature, seem to have served as the precipitant. But other modes of formation are conceivable, as for example, the manner suggested by V. Spirek, mentioned below.

As the first example we will describe Almaden[1], the most important quicksilver deposit of the globe. The town lies at the boundary between Andalusia and La Mancha, Spain, on the north slope of the Sierra Morena. The rocks consist of beds of steeply upturned shales of Silurian and Devonian age, with intercalated quartzites, which weather out in steep rocky outcrops. The strata are often interrupted by diabases and huge intercalations of igneous rocks.

The deposits consist of three quartzite beds impregnated with cinnabar. These beds have a mean thickness of 8 to 10 meters (26 to 32 ft.). The southernmost of these orebodies is called San Pedro y San Diego, the next is San Francisco and the northernmost San Nicholas. In the first named the impregnation is very strong, so that the quartz grains appear almost entirely displaced. In the other two the occurrence of the cinnabar is in the main confined to stringers and streaks, often forming parallel bands, but sometimes running cross-wise. The orebodies either adjoin barren quartzites (and in that case the boundary of the cinnabar ore is not sharp), or else the country rock is schist, in which case the ore ends suddenly.

[1] G. F. Becker: 'Geology of the Quicksilver Deposits of the Pacific Slope,' with atlas. *Monogr.* of the U. S. Geol. Surv., XIII, 1888, pp. 28–31. Fuchs and De Launay: 'Traité,' Vol. II, 1893, pp. 672–680. Caron: 'Bericht über eine Instruktionsreise nach Spanien.' *Z.* f. B. H. u. S. im preuss. St., Vol. XXVIII, 1880, p. 126.

According to H. Kuss, the zones of impregnation do not always follow one and the same stratum of the quartzite, but occasionally jump across to a neighboring stratum. An important feature is the occurrence of gliding planes in the schist and of displacements in the San Nicholas bed, as mentioned by Caron.

A little metallic quicksilver occurs with the cinnabar and pyrite, with some chalcopyrite. Gangue minerals are almost entirely lacking and comprise scanty amounts of barite and bits of bituminous substances and, according to Becker, quartz.

With increasing depth these particular deposits have become richer, while in others in the vicinity, such as Almedenejos and Las Cuevas, the reverse occurs. Between 190 and 215 meters (625 and 705 ft.) the ore carried 8 to 20% of quicksilver. From 215 m. (705 ft.) downward, the rich ores, with 20 to 85%, first appeared, and became predominant below 263 m. (863 ft.) (De Launay).

The ancient Athenians are said to have known of the cinnabar deposits in this region. Pliny describes the locality under the name of Sisapo, the mines being worked in Roman times. They were again productive during the Moorish occupancy. From 1525 to 1645 the Fugger brothers exploited the mines. Between 1564 and 1895 the locality produced about 153,000 tons of quicksilver. In the nineties of the 19th century the average annual production was 1,700 tons of metal.

A second quicksilver field on the Iberian Peninsula, which may be mentioned in connection with Almaden, lies in Asturia, south of Oviedo and near La Pena, Lada, Otero and other towns. According to A. Dory[1], the occurrences at these localities are impregnations of cinnabar and a little metacinnabarite, amalgam, orpiment and realgar in breccias and quartzites of the Carboniferous limestone, as well as in conglomerates and sandstones, and even in coal beds of the Carboniferous. The ores of this region are much poorer than those of Almaden. For the most part they contain only 0.7% of quicksilver.

Next to Almaden the Idria deposit is the most important European locality.

Idria[2], in Carniola, Austria, lies 34 km. northwest of Loitzsch, between

[1] *Revue Univers. des Mines*, Liege, Vol. XXXII, 1895, pp. 209-297.

[2] M. V. Lipold: 'Mittheilungen über die geol. Verhältn. der Umgebung von Idria und der Erzlagerstätten daselbst.' *Jahrb.* d. k. k. geol. Reichsanst., 1853, pp. 422, 864; 1856, p. 838; 1857, p. 838. A. Schrauf: 'Ueber Metacinnabarit von Idria und dessen Paragenesis.' Same journal, 1891, p. 349. 'Geolog.-Bergmännische Karten,' with profiles of Idria and views of the quicksilver deposits of Idria, published by k. k. Bergbeamten. Vienna, 1893. Edited by k. k. Ackerbau-Ministerium. With complete bibliography. F. Kossmat: 'Ueber die geologischen Verhältnisse des Bergbaugebietes von Idria.' *Jahrb.* d. k. k. geol. Reichsanst. Vienna, 1899, Vol. XLIX, part 2.

Laibach and Görz. The deposits occur in an area of Alpine Triassic rocks, which have been distributed at this locality in a very complicated way by a number of faults and overthrusts, and have been broken into a group of fault blocks, with northwest strike. This structural condition, formerly difficult of comprehension, has been cleared up recently by F. Kossmat, from whose paper we extract the instructive cross-section of Fig. 184. The main lines of the stratigraphy had already been established by M. V. Lipold. The structural features of the mines are furthermore illustrated by a longitudinal section (Fig. 185), taken from the official work on Idria. The following table is a summary of the stratigraphic succession, as it is now understood, the table also giving the symbols of the formations shown in the section.

The section is as follows, from above downward:

Alpine Trias:

6. Raibl strata.
5. Cassian limestones and calcareous slates. } Not in the mines.
4. Wengen beds, consisting of tufaceous sandstones and marls (t) with Daonella Lommeli Wism., besides intercalations of plant-bearing skonza slate (s).
3. Dolomites and dolomite breccias (d) as well as limestone conglomerates (c) of the Muschelkalk.
2. (b) Campil calcareous slate and marly limestone (kk)
   (a) Seisser sandy shale and dolomites (ssch) } Werfen strata grouped together as (w).
1. Paleozoic Gailthal shales, the so-called silberschiefer (gsch).

By a comparison of this section, showing the relative ages of the beds with the two profiles, the existence of extensive overthrusts is at once apparent.

The quicksilver deposits of Idria consist only in small part of true veins, being mainly impregnations in country rock which are in part connected with large, well defined fissures, though this is no longer demonstrable, owing to the removal of material from the workings. They appear to form stratiform deposits. In both fissures and impregnations the mineralogic character of the deposit is simple. Cinnabar is the predominant ore. Native mercury is found as an impregnation, especially in the so-called 'silberschiefer' of the upper regions. Metacinnabarite is rare. Pyrite is very frequently present, especially as a companion of native quicksilver. The most abundant gangue minerals are quartz, calcite and dolomite; barite and asphalt-like minerals, as idrialite, occur. Flourspar is rare.

The mines occur in two groups, a northwestern and a southeastern.

The only distinctly vein-like deposits are found in the southeast mine, worked through the Joseph shaft. At this place the tuffs and marly slates of the Wengen formation rest on limestones and calcareous shales of the Werfen beds, as well as on dolomites and breccias of the Alpine Muschel-

kalk and are by faulting capped by dolomites and limestones of the Muschelkalk. Among the ore-bearing fissures traversing these sediments, there are two principal veins striking northeast and dipping 28° to 30° southeast. The vein filling is sometimes one meter thick and consists of limy, shaly, breccia-like rock, heavily impregnated with cinnabar, and mixtures of

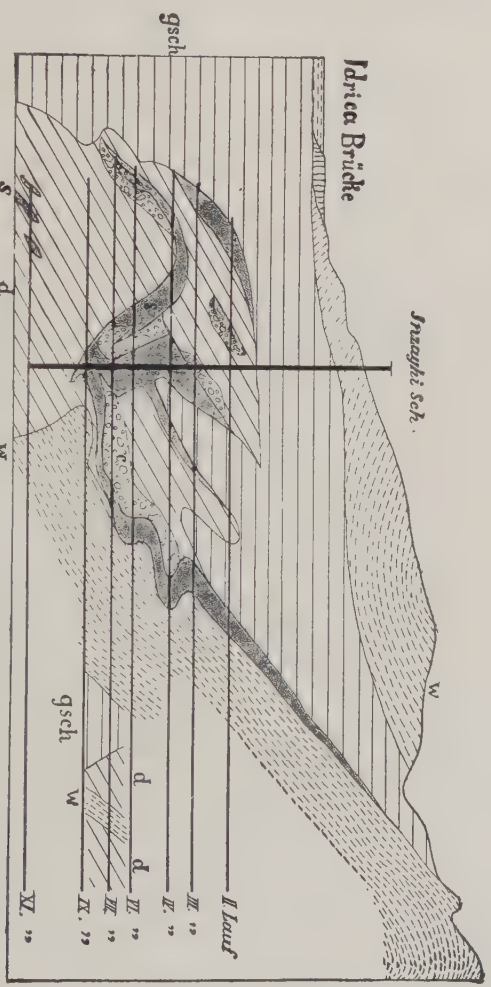


Fig. 184.—Cross-section through the Northwest mine of Idria. (F. Kossmat.) (Explanations of symbols in the text.)

dolomite and cinnabar, constituting what is called steel ore and brick ore, from the color. From these fissures the cinnabar extends far into the adjoining dolomites. A remarkable feature is the presence of the so-called "first and second riders" (thin hanging-wall veins). These strike northwest and dip 75° northeast, and thus run parallel to the main fault fissure,

which at this place cuts through Triassic rocks. These satellite fissures are also filled with brecciated masses strongly impregnated with cinnabar. Ore is also extracted in this part of the mine from a zone of

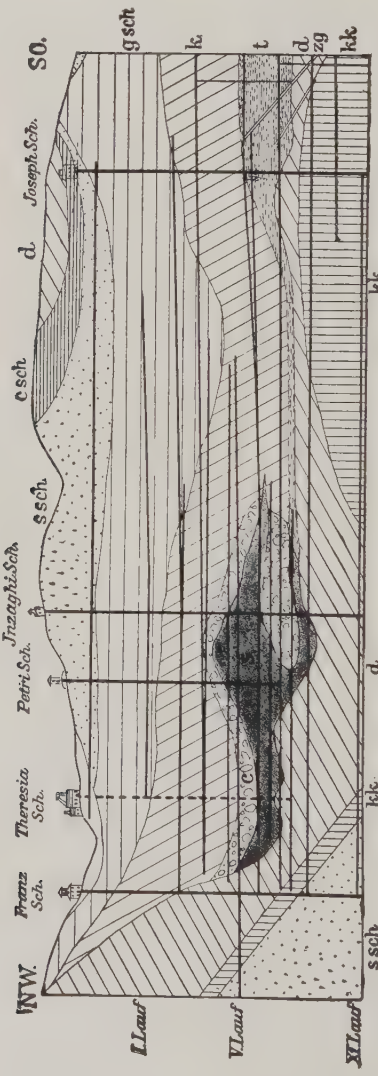


Fig. 185.—Longitudinal section through the cinnabar deposits of Idria. (J. Bloudek.) zg, cinnabar ore lodes. (Explanation of other symbols in text.)

impregnated rock lying along the bedding plane between the Guttenstein dolomite and the Wengen marly shales.

In the Northwest mine, on the contrary, the succession of rocks is different, for the Wengen tuffs and marly shales are replaced by the so-called

Skonza shales and limestone conglomerates. These Skonza shales or Lagerschiefer are dark gray to black, highly bituminous clay shales, which frequently contain plant remains. As a result of a pronounced imbricated structure of this faulted mountain block, the rocks are seen in certain sections repeated four times. The different strata have, as shown in the cross-section, been subjected to subsequent folding, together with the overthrust planes which delimit them. Extensive portions of these Skonza shales are heavily impregnated with cinnabar for 20 meters in thickness, the ore forming irregular pockets, kidneys, bunches and stringers or fillings along bedding planes. Moreover, the dolomitic conglomerates and breccias lying on and between the Skonza shales contain crystalline cinnabar regularly distributed in their cracks and fissures, while along the boundary between these rocks and the overlying Paleozoic silberschiefer (pushed over by overthrust faulting) finely divided native quicksilver is found.

The quicksilver ores, therefore, in the most important part of the Idria mines, have impregnated extensive masses of completely disintegrated rock, and have more or less saturated either highly porous or specially bituminous beds which acted as filters. The real channels of supply are not revealed. As the dislocations of the region are of Tertiary (probably Eocene) age it follows that the impregnation with quicksilver compounds is of very youthful age.

The only European district exceeding Idria in the production of quicksilver is Almaden. Its total output, from 1525 to 1895, is estimated at 58,000 tons of quicksilver. In 1898, 476.28 tons of metallic quicksilver were produced at Idria and 15 tons at Sanct Anna, near Neumarktl, in Carniola.

A noteworthy deposit of quicksilver ore occurs at Littai near the Sau. The distinctive feature of this deposit is the association of quicksilver and lead ores, the latter predominating. The ores occur in a zone 10 ft. (3 m.) thick of brecciated, shattered rock cutting an anticline of Carboniferous graywacke (a dark, tough sandstone composed of various minerals in angular fragments, firmly cemented). This orebody consists of much altered fragments of graywackes and some siderite cemented by galena, some blende, barite, chalcopyrite and pyrite. The cinnabar occurs only in and near fissures.

In the Apennines of Southern Tuscany, Italy, important quicksilver deposits are found, which are all the more interesting because their genesis is so evident. They occur within the volcanic district of Monte Amiata[1], but associated with very diverse rocks. The deposits are impregnations or bands of stringers, rather than true veins.

[1] P. de Ferrari: 'Le miniere del Monte Amiata.' Firenze, 1890. B. Lotti: 'Il

The principal deposit, at Cornacchino, west of Castellazzara, consists, according to B. Lotti, of clays impregnated with cinnabar, pyrite and gypsum. The clays are intercalated between the marly, flint-bearing limestones of the Upper Lias and represent the residue left by their decomposition by acid solutions, being the same solution from which the mercuric sulphide was precipitated.

The chemistry of this hydrothermal process has been investigated by V. Spirek. According to him the solutions contained sulphates of mercury, iron and other metals, and hydrogen sulphide, the latter gas being still given off from fissures in the earth at several points called 'putizze' in the Amiata region. At first calcium polysulphides and highly sulphuretted alkalies were formed, which, according to chemical experiments, were able to precipitate the mercuric sulphide from the solution, which meantime had become neutralized. The objection that K_2S_3 or CaS_3, by the surrender of two molecules of their sulphur, might readily be transformed into K_2S and CaS, which would redissolve the Hg that had been formed, is met by V. Spirek by the assumption that the HgS once formed was quickly enveloped in the clay mud, furnished by the corrosion of the marly limestones, and was thus protected.

The small cinnabar stringers in the underlying Liassic siliceous schists at Cornacchino are regarded by B. Lotti as secondary formations due to the removal of the ore from the overlying limestones by means of carbonated solutions.

Similar deposits of cinnabar in clay occur at Siele, between Santa Fiora and Castellazzara, where the deposit lies between marly Eocene limestones, whose fossils *(Globigerinae)* still show in the mineralized clay.

Near Montebuono cinnabar occurs in Eocene sandstones overlying Nummulitic limestones. This ore-bearing sandstone is friable, and partly disintegrated to a sand which has settled into cavities in the limestone.

At the Abbey of San Salvatore cinnabar is found in detritus on the mountain slopes, in solid Nummultic limestone, especially in the bituminous clay beds and in trachyte. In trachyte the cinnabar stringers are accompanied by marcasite and opal incrustations. Even at the present day acid sulphurous springs rise from this part of Monte Amiata. The quicksilver mining industry in the Monte Amiata region began in 1846, but

Campo cinabrifero dell'Abbadia di San Salvatore nel Monte Amiata.' *Rassegna Mineraria*, VII, No. 11. V. Novarese: 'Die Quecksilbergruben des M. A.' *Zeit. f. Prak. Geol.*, 1891, p. 60. R. Rosenlecher: 'Die Quecksilbergruben Toscanas.' *Zeit. f. Prak. Geol.*, 1894, pp. 337–353. Kloos: 'Zinnober führende Trachyttuffe vom Monte Amiata.' *Zeit. f. Prak. Geol.*, 1898, pp. 158–163. B. Lotti: 'Die Zinnober und Antimon führenden Lagerstätten Toscanas und ihre Bez. zu den quartären Eruptivg ' *Zeit. f. Prak. Geol.*, 1901, pp. 41–46. V. Spirek: 'Zinnober am Monte Amiata.' *Zeit. f. Prak. Geol.*, 1902, p. 297.

assumed an active development only after 1866. The production in 1898 was 170 tons, the maximum having been reached in 1890 with 449 tons.

The most important quicksilver district of the Balkan peninsula is Avala,[1] in Servia.

At the Schuplja Stena, on Mount Avala, 24 kilometers south of Belgrade, a serpentine stock, intruded in dark gray Cretaceous limestone, is traversed by a quartzose lode 60 to 70 m. (197-230 ft.) thick, striking northeast to southwest, and dipping about 60° northwest. This deposit is itself in turn fissured by numerous east-west lodes, formed of many quartz barite veins and stringers carrying quicksilver ores. The common-

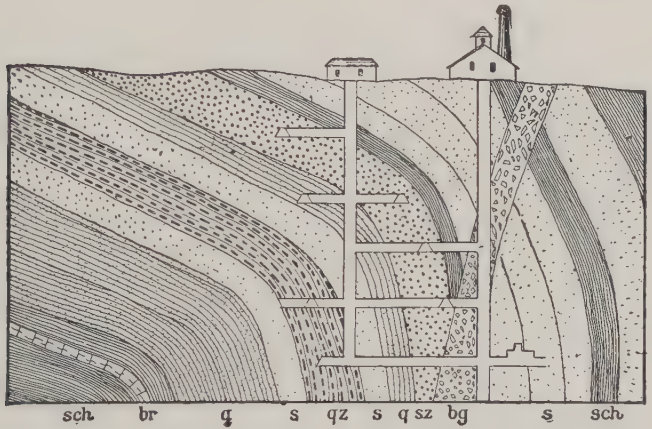


Fig. 186.—Cross-section through the cinnabar deposit of the Sophia shaft near Nikitovka. (Tschernyschew and Lutugin.)

sch, slate; br, breccia and conglomerate; q, quartzite; s, sandstone; bg, breccia vein; qz, quartzite with cinnabar; sz, sandstone with cinnabar.

est ore is cinnabar, but native quicksilver and calomel are also found. The quartz of the great northeast lode is often porous and hornstone-like and impregnated along well defined zones with iron pyrite, and with scales and fibers of a green micaceous mineral, carrying considerable chromium, and called avalite (Losanitsch). The deposit was discovered in building the Ljub. Kleritj Railway.

Quicksilver deposits are also known in Southern Russia, at Nikitovka, in the Donetz basin, along the Kursk-Kharkov Railway line. The cinnabar is, according to Th. Tschernyschew and L. Lutugin[2], found in fault fissures, in

[1] A. v. Groddeck: 'Ueber das Vorkommen von Quecksilbererzen am Avala-Berge bei Belgrad in Serbien.' *Preuss. Z. f. Berg-, Hütten- und Sal.-W.*, 1885, Vol. XXXIII, p. 112.

[2] *Guide des Excursions du VII. Congrès Géologique*, 1897, XVI, pp. 36–45.

coal, and as impregnations in the adjoining carbonaceous sandstones, quartzites and coal beds. The cinnabar is frequently accompanied by stibnite, pyrite and desmine. The accompanying section, Fig. 186, shows the structural conditions. The output in 1904 was 392 tons.

The quicksilver mines of the Palatinate, although long since worked out, are of scientific interest. They lie in the eastern part of the Palatinate-Saarbrücken coalfield.

According to von Dechen[1] and von Gümbel[2], the ores occur partly in veins, partly as impregnations associated with the veins, in beds of the coal series and the eruptive rocks intruded in them. At the Potzberg the veins occur in Carboniferous sandstone and clay slate, at Mörsfeld in the melaphyre conglomerate, claystone conglomerate and claystone, at Rathsweiler, Erzweiler and Baumholder in melaphyre; at Königsberg, near Wolfsberg, in quartz porphyry. Numerous parallel stringers accompany the lodes, and the country rock is ore-bearing, especially if it is sandstone and claystone. Some of the lodes have a remarkable length for this type of vein. The Gottesgabe vein at Landsberg is 900 meters long. In other cases the veins lie side by side with overlapping ends, forming a lode system 1 to 3 miles long, as at Stahlberg and at Kirschheim-Bolanden. The pay ore in these veins decreases rapidly in value below 656 ft. (200 m.)

The vein filling consists mainly of clay, in which the ore minerals, chiefly cinnabar, occur as veinlets, streaks or druses, more rarely in scales or ribbons of ore. Native quicksilver, amalgam, calomel, bituminous cinnabar and mercurial tetrahedrite also occur in the Landsberg "Black Vein." In rare cases pyrite, iron and manganese ores, galenite, native silver, chalcopyrite, stibnite, calcspar, barite, quartz, hornstone, ferruginous quartz and asphalt occur as accessory minerals, the gangue minerals forming, as a rule, only thin stringers or crusts.

A cinnabar deposit in Saxony[3], near Hartenstein, which has been known since the 16th century, presents unusual mineralogic characters.

The deposits occur as impregnations of chloritic clay and hornblende-slates of the Phyllite formation. The ore forms stringers and kidneys of quartz, feldspar, brownspar, calcspar and ironspar, accompanied by a little chalcopyrite and pyrite. At the Weidlich Stolln, which was operated towards the end of the 18th century, a lode 0.25 m. (0.8 ft.) thick, consisting of quartz, brownspar and ferruginous clays, was encountered near these impregnations. The cinnabar impregnation was also found in the Beständig

[1] *Karsten's Archiv.*, 1848, Vol. XXII, p. 375.

[2] W. v. Gümbel: 'Ueber die Quecksilbererze in der Pfalz.' *Verh.* d. naturw. V. f. Rheinl. u. Westf., VII, 1850, p. 83 *et seq.*

[3] H. Müeller: 'Der Erzdistrict von Schneeberg.' Gangstudien, III, 1860, pp. 170–174.

Glück Stolln, where it was confined to the vicinity of a small lode which was itself barren.

The greatest cinnabar deposits outside of Europe are those of California, described by Becker[1]. The deposits are mainly in the Coast Range, formed of folded metamorphosed Neocomian (Early Cretaceous) slates, with later intrusions of granite, quartz porphyry, andesite, rhyolite and basalt. The tilting and dynamo metamorphism of the Neocomian strata (*Aucella* beds) took place as early as the Middle Cretaceous, and was repeated with accompanying active volcanic eruptions. These eruptions, with which the quicksilver deposits are genetically connected, continue into post-Pliocene time.

The deposits consist of very irregular veins, often as the chambered veins described by Becker, or forming stock-like bodies which extend laterally from the lode into the shattered or porous country rock.

The following are the most important mining districts, given in the order of location from north to south: Sulphur Bank and other mines near Clear Lake in 39° north latitude, Great Western, New Almaden, northeast of Santa Cruz and New Idria. Sulphur Bank is described elsewhere.

The Great Western mines lie near the extinct volcano of Mount Saint Helena, in a region of metamorphic slate, intruded by andesite and basalt. The deposit forms a steeply inclined tabular orebody lying along the contact between slightly altered sandstone and an opalized serpentine. The ore contains cinnabar with pyrite in a quartzose gangue, with bituminous matter.

The New Almaden is the largest and most important of the cinnabar mines of California. The ores consist of cinnabar with some native quicksilver, and accessory pyrite, marcasite and chalcopyrite, in a gangue of quartz, chalcedony, calcspar, dolomite, and magnesite. The orebodies form stockwork 'chambers,' along two distinct lode fissures, in crushed and greatly disintegrated sandstones, serpentines and diabase-like metamorphic rocks.

A similar state of affairs prevails at New Idria, where the ore occurs within crush zones of the Neocomian strata. Bitumen is also present in these deposits.

G. F. Becker insists that no metasomatic replacement occurs in the Californian cinnabar deposits. He states that there has been no replacement of the country rock by the ores, but merely a filling of the existing pores, cracks and fissures. He regards the ores and gangues as deposits from hot springs which brought their mineral load from deep lying rock bodies. In 1902 California produced 29,199 flasks of 76.5 lb. of quicksilver,

[1] G. F. Becker: 'Quicksilver deposits of the Pacific Slope.' *Monogr.* XIII, U. S. Geol. Survey, Washington, 1888.

valued at $1,271,502. The Terlingua deposits of Texas produced 5,2[illegible] flasks in 1902. The ores occur as pockets of cinnabar with calcite gangue in fissure veins[1] cutting Cretaceous limestones. The total production of the world for 1904 was 118,711 flasks, or 4,010 metric tons.

In South America the cinnabar lodes of Huancavelica[2] in Peru were in former times of exceedingly great importance, having furnished 52,000 tons of quicksilver between 1571 and 1850. The town lies on the east slope of the western main ridge of the Cordilleras. The rock consists of Jurassic slates, conglomerates, sandstones and limestones intruded by trachytes. In the vicinity of the town are hot springs which deposit sinter so abundantly that it serves as building stone. They are the last phase of a dying volcanic activity. The Santa Barbara mine, close to the town, is the most important. The deposit consists of impregnations of cinnabar, pyrite, arsenopyrite and realgar in a sandstone.

The Huitzuco mines in Guerrero, near Chilpancingo, Mexico, should be mentioned in this connection. The ore is livingstonite, an antimonial sulphide of mercury, according to F. Pagliucci. It occurs in veins and replacements in cretaceous limestones, connected with well-defined hot spring conduits[3].

Recently the cinnabar ore lodes of Punitaqui in Chile have attracted attention[4].

The Chinese Empire was formerly a large producer of quicksilver, and contains, according to R. Pumpelly, quicksilver deposits in ten out of eighteen provinces of the empire, the most important being those of the province of Kwei-Chau. The mines at Kaitchou, a town near the provincial capital, Kweijang, have recently been re-opened by an Anglo-French Company.

Quicksilver ore lodes likewise occur in Asia Minor, at Habiler and at Haleköi[5].

In Australia also quicksilver deposits occur at Yulgibar in the basin of Clarence River in New South Wales, where three quicksilver veins have been opened. New Zealand contains deposits formed and now being deposited by the hot springs at Oheawai. (Parks.)

[1] B. F. Hill, *Am. Jour. Sci.*, 4th ser., Vol XVI, pp. 251-252. 'The Terlingua Quicksilver Deposits,' *Bull.* No. 4, Univ. of Texas Mineral Survey, Oct., 1902.

[2] G. F. Becker: *Monogr.* XIII, U. S. Geol. Survey, p. 21.

[3] F. D. Pagliucci, in *The Engineering and Mining Journal*, March 2, 1905, p. 417. 'Mines and Metallurgy of Quicksilver in Mexico,' *Trans.* Inst. Mining and Metallurgy, London, Vol. IV, p. 69, 1895-6.

[4] A. Götting: 'Die Erzgänge zu Punitaqui in Chile.' *Zeit. f. Prak. Geol.*, 1894, p. 224.

[5] K. E. Weiss: 'Lagerstätten in Westlichen Anatolien.' *Zeit. f. Prak. Geol.*, 1901, No. 7.

C. GENERAL DESCRIPTION OF MINERAL VEINS.

(Continued from page 226.)

Differences in Vein Contents at Different Depths.

Since the time of Von Cotta it has been customary to describe as *primary* those differences below the water level which are observed in the character of the vein filling at different depths. This change may consist in a different mineralogic composition, and perhaps also in the structure of the original filling. The different sections of a vein might, therefore, belong to entirely different vein types under the classification adopted. Such cases are, however, comparatively rare. On the contrary, difference between the character of the vein filling near the surface and in depth are extremely common in most of the vein deposits as well as in stratiform and stocklike deposits. These superficial changes are *secondary,* and due to a superficial alteration of the deposit and the influence of descending waters. Let us first consider some examples of the first kind.

Changes in Character of Primary Vein Filling with Depth.

There was in former times a widespread belief that veins gradually became barren as the distance beneath the outcrop increased. This change in character of primary ore would be, if true, very important from the practical point of view. This theory was probably founded upon the well known change in the veins when the transition from the gossan into the undecomposed primary vein filling occurs, in which of course a sudden and great impoverishment was naturally noted in many cases. From this it was inferred that the impoverishment would continue downward. This assumption is probably the basis of the older views that gold veins grow barren in depth, a view formerly current in California. Recent deep mining of gold veins in that country and in Australia have dispelled this fear. We know, for example, that some lodes in Victoria are still workable at a depth of 4,000 ft. In many cases local zones of impoverishment were encountered, which, by reason of the older, less perfect mining methods, or insufficient funds, could not be passed through. This gave rise to a belief in the impoverishment of veins in depth. A few courageous, far-seeing men had to engage in a laborious fight against this prejudice, as, for example, Freiherr von Herder[1], who planned in 1838 the

[1] Freiherr von Herder: 'Der tiefe Meissner Erbstolln.' Leipzig, 1838.

deepest drift in the Freiberg field, which was afterwards driven and finished (the Rothschönberger Stolln). In some cases, indeed, the idea of an impoverishment in depth proved to be true, as for example, in the so-called cobalt ledges or 'rücken' of Thuringia, which commonly become barren and end in the older schists.

A great number of observations, however, are now at hand, which indicate a variation in the primary mineralogic composition of veins at different depths. A few of them may be mentioned.

In the Himmelsfürst mine at Brand, near Freiberg, the Silberfund Stehende above the 7th level is a typical example of the rich brownspar deposit (carbonspathic lead formation); between the 7th and 9th levels it belongs to a mixture of that type and a pyrite blende lead deposit; below the 9th level it is of the latter class entirely.

In the Junge Hohe Birke mine at the same locality the Prophet Jonas Stehende and other lodes belong, in the upper regions, to the copper deposits; in the deeper zones to the pyritous-blende lead class.

In general it is said that in the deep workings on the Freiberg lodes it has been noted that the amount of pyrite becomes greater, and that of galena less, with increasing depth. Thus in the once rich Peter Stehende of the Alte Hoffnung Gottes mine, and its northeastern continuation, the Einigkeit Morgengang, at a depth of somewhat more than 1,650 ft. (500 m.), the galena is almost entirely replaced by pyrite and blende. Moreover, the galena that does occur has become poorer in silver. The same is true of the Christliche Hilfe Stehende. On the other hand, in the Crown mines, at Freiberg, this increase in pyrite has, indeed, been noticed, but careful assays of selected samples of pure galena show no regular or orderly decrease in the amount of silver in the galena. In a few lodes the laboriously accurate investigations by A. W. Stelzner and F. Kolbeck did, indeed, demonstrate a gradual and constant decrease of the silver content with increasing depth, but in others they showed the contrary. The more accurate results are yet to be published by the last named author.

Concerning the mines in the Upper Harz, F. Klockmann writes[1]: "It is usually stated that with an increasing depth of the mines the sphalerite appears in larger amount" (as compared with galenite). This is confirmed by Zirkler[2]. The silver content of the galenite also decreases slowly in some lodes of that locality with increasing depth. According to Zirkler the silver content calculated for 60% lead decreases as follows in the ores: (1) of the Burgstädt main lode, with 85 feet (26 m.) difference in depth

[1] *Berg- und Hüttenwesen des Oberharzes*, 1895, p. 48.

[2] Zirkler: 'Ueber die Gangverhältnisse der Grube Bergmannstrost bei Clausthal.' *Glückauf*, Essen, 1897, p. 84.

from 0.0889 to 0.0609%; (2) of the middle stringer, with 410 ft. (125 m.) difference in depth, from 0.0865 to 0.0522%; (3) of the Bergmannstrost Hangande stringer, with 866 ft. (261 m.) difference in depth, from 0.0732 to 0.0467%.

Similar changes in depth of silver lead ores are noted by Weed[1] in the mines of Castle Mountain district, and those of the Barker districts, both in Montana. The galena becomes less and less and the zinc and pyrite increase until the latter predominates in depth. The same is true also at Elkhorn at 2,300 ft. in depth.

However, these conclusions seem as yet based on too small a number of examples.

Still more striking differences in depth occur in tin veins: According to B. von Cotta the lodes formerly worked at Seiffen, in the Erzgebirge, are said to have carried in the upper regions mainly tin ore; farther down more copper ore[2]. According to H. Müller[3], however, this was probably due merely to an accidental distribution in the regions in question.

This variation is far more strikingly and conclusively demonstrated by the deep mine workings of the tin ore lodes of Cornwall, as illustrated by the plat of the Dolcoath mine shown on page 214. As another zone of tin ores is found below the copper zone, the change may not be due to depth alone.

Similar phenomena have been observed in manganese veins. According to De Launay[4] and Vogt[5], the manganese deposits occurring in the granites of Romanèche (Saône-et-Loire), in France, carry barytic psilomelane and hematite, together with quartz, barite, a little fluorspar, and traces of calcspar, the psilomelane predominating in the upper region, the hematite in the lower region. De Launay, however, thinks it not impossible that this phenomenon may be of secondary origin.

Secondary Alteration of the Minerals in Veins.

Superficial Alteration of Ore Deposits (Gossan Formation).

The term *superficial alteration* of ore deposits applies to those changes in composition and structure which the ore deposit undergoes above ground-

[1] Walter Harvey Weed: 'The Castle Mountain Mining District,' *Bull.* 139, U. S. G. S. 'The Mines of the Little Belt Mts., 20th *Ann. Rep.* U. S. G. S., Pt. 3, 1900. 'The Elkhorn District, Montana,' 22d *Ann. Rep.*, U. S. G. S., Pt. 2, 1902. See discussion on orderly vertical distribution of ore in veins and theory for it in 'Boulder Hot Springs of Montana,' 21st *Ann. Rep.* U. S. G. S., 1901. p. 249.

[2] B. v. Cotta: 'Erzlagerstätten,' II, p. 23.

[3] H. Müller: 'Die Erzgänge des Freiberger Bergrevieres,' 1901, p. 133.

[4] L. de Launay: 'Compte-Rendu du VIII. Congr. géol. intern.,' 1900, p. 211.

[5] J. H. L. Vogt: 'Problems in the geology of ore deposits,' *Trans.* Amer Inst. Min. Eng., February, 1901, p. 40.

water. The sharp distinction between the conditions above ground-water level, the vadose region, and those below that level, the profound region, was brought out by F. Posepny[1]. The ground-water level in the sense it is used here means the plane, or in cross-sections the height, to which the atmospheric water rises after it has entered the deep regions. A hydrostatic basin which this water fills below that line will in most cases consist of a most complicated and ramified system of fissures, joints, capillary spaces and the gaps between the mineral components or the grains of porous rocks. The elevation of the ground-water line will depend on the relative position of the channels in which the underground water circulates, either towards its exit at the surface of the globe or towards a deeper reservoir separated from the upper porous bed by relatively impervious strata, and thus reached by the water only through a circuitous route.

In general the ground-water level follows the inequalities of the earth's surface, rising with the slope of the land from river valleys and from the sea coast, places where its position coincides nearly with the surface of the ground. In mountains containing numerous wide cavities, as in high limestone regions where the atmospheric water may descend to great depth in the great underground rivers, the ground-water level may lie below 1,640 ft. (500 m.) as reported, for example, by S. F. Emmons from the Tintic district in Utah[2]. In a scientific examination of ore deposits, it is desirable to ascertain as accurately as possible the natural position of the ground-water level, since a knowledge of it is valuable in many respects, both theoretically and practically. Attention must also be directed to alterations of the ground-water level in different geologic epochs.

The paragraphs which follow deal with the chemical changes above ground-water level, not only of veins, but to all ore deposits, since these changes depend not on the form and genesis, but solely on the chemical composition of the unaltered deposits. In the uppermost part of the earth's crust, above the line of permanent underground water, and to some distance below it, most of the metallic minerals of ore deposits undergo alteration through the action of atmospheric air, and lower down by the water which has seeped down and carried, in addition to oxygen, various amounts of carbonic acid, organic acids and perhaps ammonium chloride and hydrogen sulphide. The new minerals, developed in this way, are of course as varied as in the composition of the primary deposit. In general, the sulphide ores will change to oxidic ores of various kinds, carbonates and sulphates, also to native metals, and to chlorine, bromine, and iodine com-

[1] F. Posepny: 'Ueber die Genesis der Erzlagerstätten,' 1895, p. 24.

[2] *Trans.* Am. Inst. Min. Eng., 1900. See also *Tintic Special Folio*, Folio No. 65, U. S. Geol. Survey, 1900.

pounds, phosphates and silicates. The most widely distributed final products of decomposition are brown and red hematite, which occur even where there are no true iron deposits. As the new minerals are very readily recognized by the red or brown coloring of the outcrop, the uppermost and decomposed part of a deposit, especially of a vein, is often described as the iron hat (*eiserne hut* in German, *chapeau de fer* in French), though the English speaking miner calls it gossan, a term originating in Cornwall.

The iron oxides, particularly limonite, form the firm skeleton, as it were, of the gossan, about which the softer or more soluble new minerals accumulate. If the latter are carried away eventually, the outcrop has finally a thoroughly characteristic, porous, cellular, often slag-like structure. Hence such terms as "burnt reefs" for outcrops of this kind. The coloring in such cases is blackish, especially where psilomelane and other manganese ores accompany the limonite, as is often the case.

When comparatively little quartz is present, the ferruginous skeleton remaining may be strongly compressed by lateral pressure and dislocation. In this case the outcrop and gossan of mineral veins are narrower than the unaltered veins below the zone of decomposition. The outcrop may indeed often present an inconspicuous or even barren and uninviting appearance, as for example in the copper veins of Butte, Montana.

The reddish color is not always present. Quite often when copper sulphides predominate in unaltered veins, the gossan is brightly colored, giving rise to the term used by the miners of Spanish South America, *colorados* or *pacos* for the red ores directly at the outcrops; *mulattos* for the deeper zone where simple sulphur compounds usually predominate, and finally *negrillos* for the still deeper dark-colored sulphur compounds of the normal unchanged orebodies.

As the gossan ores yield readily to amalgamation they are called *metales calidos* in Chile, that is, warm ores, because in the presence of iron and an appropriate lye they amalgamate directly with quicksilver with development of heat, which is not the case with sulphidic *metalos frios,* that is to say, the cold ores found at greater depths.

The greater the amount of sulphide ore in the unaltered vein, the greater the amount of secondary material and the more abundant and conspicuous the gossan. It was commonly found that mineral veins devoid of gossan zones rarely repaid the labor of the prospector; hence the much quoted proverb:

Es thut kein gang so gut,
Er hat nicht einen Eisern Hut;

or, as they say in Cornwall:

Gossan rides a high horse.

Climatic conditions have a great influence on the formation of the gossan. In rainless, arid regions, as in South Africa, the Atacama Desert of Chile, the Great Basin Desert of North America, and in the interior of Australia where the aqueous degradation is slight, the destruction of a deposit is due less to rain than to the abrupt change of temperature, resulting from the intense heat of the day, followed by intense radiation. This, combined with the corroding work of the wind, which leaves the heavy metallic particles behind, while carrying away the lighter products of decomposition, results in a gossan especially rich in ore. The metallic compounds are in such regions concentrated to a high degree. Of course, such tracts are not entirely devoid of rain and, moreover, although they are often deprived of it completely for long periods, yet they enjoy at any rate the benefit of dew, so that even there the alteration is perhaps mainly accomplished in the aqueous way. But while elsewhere the soluble newly formed substances are washed off into brooks and rivers, in the arid regions they remain in the gossan, or merely penetrate along cracks and fissures into the similarly decomposed country rock, so as to render the latter also workable in many cases. This is especially true of the newly formed particles of native metal, particularly gold. The rapid decrease in value of gold veins with increase in depth down to the undecomposed zone, is well known. As a result, mining excavations in the zone of oxidation as a rule are much more extensive than at greater depths, where the strong secondary impregnation of the disintegrated rock disappears, or at any rate is greatly diminished[1].

Another peculiarity of the gossan deposits of arid regions is their wealth in metallic chlorides, bromides and iodides, especially of silver. In such arid regions, particularly in enclosed drainage basins, the saline contents of the solutions, arising from the decomposition of a great variety of silicates, are apt to be concentrated in the topmost layer of the solution through the continued strong evaporation of the water. Thus the water in the gold mines of West Australia is often found to be brackish. A sample of water from the Great Boulder mine at Kalgoorlie, according to T. A. Rickard, contained 9% of table salt. Quite generally we find that the countries which contain the so-called 'salt pans' in depressions are also distinguished by a great abundance of chlorine, bromine and iodine compounds in the weathered zone of the rich ore deposits of the region.

Another important factor, according to Emmons[2], is aridity, so that in arid regions the ground-water level lies much deeper than in humid regions.

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes,' *Trans.* Amer. Inst. Min. Eng., 1898, Vol. XXVII, pp. 564-668.

[2] 'Genesis of Ore Deposits,' 9th *Ann. Rep.* Inst. of Min. Eng., p. 438.

Hence the slight rainfall is able to seep down very far before it reaches the masses of water which preserve the original ore of a deposit, and thus this descending water is able to concentrate certain metals throughout the route traversed, as will be explained below. As, moreover, there is no vigorous erosion and denudation in such regions, the same influences may affect parts of a vein to a great depth and for a great length of time.

The minimum development of the gossan is seen in the Northern Hemisphere in the region glaciated in Pleistocene time. In such countries the glacier has almost entirely removed the oxidation zone of the deposits, and no new zone of notable thickness has had time to develop, so that the normal composition of the orebody is encountered directly below the sod. A striking example of this is found in the outcrops of the magnetic iron ore deposits of Sweden, which are almost devoid of a limonite cover, while the zinc-blende deposits of that region are devoid of a calamine gossan.

The chemistry of the gossan[1] varies in character with the complexity of the composition of the original deposit.

We will first consider only those constituents of the gossan for whose development the oxygen or carbonic acid content of seepage water suffices. Even below ground-water level the water still contains some oxygen, but its percentage rapidly decreases with increasing depth, as was proved by Lepsius by means of water samples from drill-holes[2]. Some alterations are therefore possible even below the gossan.

I. *New Substances Developed in the Zone of Oxidation.*

We must begin by recalling that the ore minerals are attacked by the oxygen of the air in very diverse degree, and therefore also with greatly diverse rapidity, as proven by laboratory experiment. Of course in nature the order of succession in this process will frequently vary, because of the influences exerted by the mode of mutual blending of the ores and gangues; the exposed surface of the various substances is the determining factor in the individual case. Thus, according to Emmens[3], the more important sulphides are attacked by decomposition in the following order: (1) marcasite, (2) pyrite, (3) pyrrhotite, (4) chalcopyrite, (5) bornite, (6) millerite, (7) chalcocite, (8) galenite, (9) zinc-blende.

The great tendency to decomposition of marcasite in moist air is well known to all who have to preserve samples in collections. The first stable

[1] J. Roth: 'Allgemeine und chemische Geologie,' Vol. III, Berlin, 1879-1893. R. Brauns: 'Chemische Mineralogie,' Leipzig, 1896.

[2] Ber. d. Deutsch. Chem. Ges., Vol. 18, p. 2487.

[3] Stephen H. Emmens: 'The Chemistry of Gossan,' *The Engineering and Mining Journal*, 1892, p. 582.

products of the weathering of this ore as well as of pyrite and pyrrhotite are iron-vitriol, acid iron sulphates, and sulphuric acid. They are recognized everywhere by the efflorescence upon specimens in the museums and in the corrosion of the attached labels. The same substances are also present in mine water. The sulphate, however, is quickly further oxidized into various ferric sulphates, among others the neutral sulphate. The reaction may be represented by the following equation:

$$2\,FeSO_4 + O + H_2SO_4 = Fe_2(SO_4)_3 + H_2O.$$

The neutral ferric sulphate thus formed undoubtedly constitutes the principal ingredient of our mine waters (see notes on mine water). It sometimes occurs pure and unmixed, as a syrupy substance in mine cavities; for example in 1896 small outflows of this compound, quickly drying in the air, were seen oozing out of the old stope filling in the Alte Mordgrube near Freiberg. Its occurrence at Coquimbo in Chile is well known (coquimbite). Iron sulphate is extremely common in the mine waters of Butte, Montana, where it sometimes forms stalactites and incrustations in the Silver Bow and other mines.

The neutral ferric sulphate in aqueous solution is believed to play an active part in the further decomposition of pyrite masses, whose first oxidation results in the formation of monosulphides:

(1) $FeS_2 + Fe_2(SO_4)_3 = 3\,FeSO_4 + 2S.$
(2) $2S + 6Fe_2(SO_4)_3 + 8H_2O = 12FeSO_4 + 8H_2SO_4.$[1]

The ferrous sulphate thus formed absorbs in its turn oxygen from the air, and is again changed into neutral ferric sulphate, and may thus again attack monosulphides, until finally all the marcasite, pyrite and pyrrhotite are destroyed. This hypothesis lacks experimental quantitative verification.

Let us consider the alteration of chalcopyrite. The empiric composition $CuFeS_2$ may be written either $Cu_2Fe_2S_4$ or Cu_2S,Fe_2S_3, since one is justified in considering it as a cuprous salt of the acid, hydrated sulphide of iron ($HFeS_2$). Acid iron sulphate may in this case also act as a carrier of oxygen and assist decomposition. Similarly bornite, $3Cu_2S,Fe_2S_3$, and rarely ferrous sulphides, such as iron nickel pyrite, are attacked. The non-ferrous sulphides, on the contrary, are attacked by the solutions, which, in consequence of the decomposition just described, are still rich in acid iron sulphate.

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S.$$
$$PbS + Fe_2(SO_4)_3 = PbSO_4 + 2FeSO_4 + S$$
$$ZnS + Fe_2(SO_4)_3 = ZnSO_4 + 2FeSO_4 + S.$$

But, whatever the process of alteration may be, the final products are always sulphates, most of which are soluble and readily carried off in solution, but sometimes are segregated and redeposited. Reference may

[1] H. N. Stokes: 'On Pyrite and Marcasite,' *Bull.* 186, U. S. Geol. Survey, 1901, p. 15.

here be made to the considerable quantities of anglesite (lead sulphate) found in the gossan zone of the Leadville galena deposits and at Tarapaca, and to the fine crystals of anglesite of Monteponi in Sardinia. Although the sulphur in the reactions outlined above is usually oxidized at once into SO_2 and H_2SO_4, yet it sometimes remains in the gossan and is then found alongside of the carbonates and sulphates of lead, etc., as at Leadville and Monteponi (on anglesite). Friable sulphur also occasionally occurs in the cubical cavities left by the dissolution of the pyrite of gold quartz veins and is sometimes associated with native gold (West Australia).

A local accumulation of sulphates is especially formed by dry climate, as in alunite deposits in Colorado, described by Cross and in the deposits of solid melanterite in veins near Whitehall, Mont. Even the readily soluble copper sulphate may then sometimes persist and in rare cases a workable deposit of this substance is known, as in the Bluestone mine, Nevada, and the deposit at Copaquire in the Huatacondo Valley, about 42 miles (70 k.) east of Challacollo in northern Chile. The latter deposits occur, according to Oehmichen[1], in a region, west of the detrital deposits of the Pampa Tamarugal, in which the strongly folded and upraised Mesozoic sediments of the Cordillera are intruded by a granitic rock. For a considerable distance and thickness, near its contact with the sediments, this rock contains stringers and impregnations of blue copper sulphate (chalcanthite) associated with less amounts of malachite, azurite and chrysocolla, besides pyrite, brown hematite and gypsum. A little chalcopyrite seen in rare instances is the only primary ore. Copper salts also occur with molybdenite on fissure walls, and the granite wall rock is strongly decomposed where penetrated by the impregnation. The copper content of the deposit, which is to be extracted by mere leaching with water, has been ascertained to be 2.5 to 3%. Mention should be made of the stalactitic deposits of blue vitriol formed in the workings of the Mountain View and the Silver Bow Mines at Butte, Montana, formed by surface waters seeping down through old stopes filled by low-grade ore.

A great part of the various sulphates formed by weathering are further oxidized; thus the iron sulphate results in the formation of limonite, as in the following equation:

$$12FeSo_4 + 6O + 6H_2O = 4Fe_2(SO_4)_3 + 2Fe_2(OH)_6.$$

Besides oxygen, the carbonic acid contained in the seepage water from above is commonly active. The process is as follows: Since most veins contain calcite or other carbonates, these are dissolved by the carbonated

[1] H. Oehmichen: 'Eine Excursion zur Kupfersulfat-Lagerstätte von Capaquire,' *Zeit. f. Prak. Geol.*, 1902, pp. 147-151.

water. When such solution encounters iron sulphates, the reaction is as follows:

$$Fe_2O_3(SO_3)_2 + 2Ca\,CO_3 = 2Ca\,SO_4 + Fe_2O_3 + 2CO_2.$$

Hence, in the zone of decomposition of veins, gypsum and red hematite are not infrequently associated. The process is somewhat different when the carbonate encounters either lead or zinc sulphate.

$$Pb\,SO_4 + Ca\,CO_3 = Pb\,CO_3 + Ca\,SO_4.$$

Thus cerussite or smithsonite, as the case may be, may occur with gypsum. Both minerals will crystallize out at once if their solutions encounter calcium carbonate, which is more easily soluble than the carbonates of lead and zinc. The precipitation of cerussite is still going on in many old mines. Thus, according to A. von Groddeck[1], the levels of the Elizabeth mine at Bleiberg near Commern, when re-opened after an interval of one hundred years, showed coatings of this mineral of the thickness of a finger.

The accumulation of carbonate of zinc (smithsonite) and copper (malachite and azurite) in the gossan is an analogous process. Melaconite, an earthy copper oxide of blackish color, and cuprite (cuprous oxide) usually accompany the copper carbonates.

The formation of cuprite may be represented by the following equation:

$$2Cu\,SO_4 + 2Fe\,SO_4 + H_2O = Cu_2O + Fe_2(SO_4)_3 + H_2SO_4.$$

Sometimes the cuprite appears in large kidney-shaped masses, as in the Cobre mine, Santiago, Cuba, and the Luise mine, near Illapel, in Chile. These brilliantly colored secondary copper ores gave rise in Chile and elsewhere in South America to the term *metales de color* for the ores of the gossan in the silver-copper ore lodes of that region.

The sulphuric acid formed in the last equation combines at once with carbonates if they are present, for instance, in the presence of calcite it combines into gypsum. If it remains free, its action upon cuprite may lead to the formation of native copper, as is shown by pseudomorphs of native copper after cuprite: $Cu_2O + H_2SO_4 = CuSO_4 + Cu + H_2O$. The mere presence of ferrous sulphate suffices for this purpose: $3\,Cu_2O + 2FeSO_4 = 4Cu + Fe_2O_3 + 2CuSO_4$.

On the other hand, metallic copper is frequently formed by the reduction of the sulphate by decaying or carbonizing organic substances. Thus native copper was found on the timbers of a drift, in the Rio Tinto mine, dating back to Roman times, on old mine timbers in the copper mines of Kawan Island[2], New Zealand, and elsewhere.

[1] A. von Groddeck: 'Lehre von den Erzlagerstätten,' p. 288.

[2] W. H. Baker: *Zeit. f. Prak. Geol.*, 1901, pp. 37, 367.

In the case of zinc, nickel, cobalt, etc., analogous reactions are not possible, and accordingly these metals are not known in the native conditions in nature.

Native lead is very rare in nature, and conditions favorable for its presence in the gossan occur only in very exceptional cases. It is possible that lead suboxide (Pb_2O) is first formed, which is decomposed by sulphuric acid into Pb and $PbSO_4$; a deoxidation by anhydrous arsenious acid has also been suggested[1]. The association of lead with manganese ores is also remarkable.

Native silver, so often found in gossan and in the deeper regions as well, is manifestly in most cases a secondary product. Masses of pure silver weighing between two and three hundred pounds were found in the gossan of the Planchas de la Plata mines, Sonora, Mexico. It may be formed in many ways, but in most cases the following equation probably represents the usual process:

$$Ag_2SO_4 + 2FeSO_4 = 2Ag + Fe_2(SO_4)_3.$$

However, its precipitation from solution may be also caused by the reducing action of organic substances, either originally present in the wall rock or secondarily introduced from above. That a reduction really occurs is proved by the casts of fossil fish (*Palaeoniscus*) in the Mansfeld copper shale, some rare specimens of which are known, showing silver plated scales, though ordinarily sulphidic ores have been precipitated on the scaly envelope of these fishes.

In the Freiberg veins native silver has very frequently been deposited along the schistosity planes of the decomposed gneiss wall rock, so that the country rock seems to take part in the reactions, perhaps by means of its ferrous compounds (though there is not a necessary sequence, as actual deposition may take place at some little distance from the location of the reducing agent). At greater depths the secondary production of native silver from argentite may very often be observed[2], and conversely native silver has occasionally been altered back into argentite. Less frequently one observes the reduction of proustite and other rich silver ores to the native metal. Vogt[3] gives illustrations of many specimens from Kongsberg in which the native silver is seen studding crystals of argentite and proustite, in tooth-shaped and moss-shaped aggregates, as if it had grown out of them. Similar instances are not rare elsewhere. In explanation of the process, G. Bischof[4] refers to experiments in which native silver is

[1] S. H. Emmons, *op. cit.*

[2] See what is said later about formation of native silver and the sulphide by reaction between silver sulphate and glance.

[3] J. H. L. Vogt: *Zeit. f. Prak. Geol.*, 1899, p. 113.

[4] G. Bischof: 'Chem. und Phys. Geologie,' Vol. III, 1866, pp. 851-857.

formed when heated water vapor or hot air is passed over silver sulphide. The reaction is as follows:

$$4Ag_2S + 4H_2O = 8Ag + H_2SO_4 + 3H_2S.$$

Sometimes, indeed, a large sliver of silver adheres to a small crystal of argentite whose disproportionate area without any notable decrease of attachment seem to make this explanation inapplicable.

Lastly it is known that native silver can be precipitated from solutions carrying silver sulphate by chalcopyrite, and various other sulphides form argentic sulphide.

After this digression into the reactions taking place below the gossan, let us consider the occurrence of free gold in the true gossan, which is a feature of many deposits even when the deeper zones contain no visible free gold. That the free gold in the gossan is in most cases derived from decomposed auriferous iron pyrites and other sulphides, is beyond doubt. It is more difficult to decide whether the gold was mechanically enclosed in the pyrites or chemically combined. Probably both cases occur in nature. The latter case seems sometimes to be indicated by the distribution of the free gold. Thus W. Mietzschke[1] described grains and crystals of iron pyrite transformed into limonite, with inclusions of native gold. When these limonite pseudomorphs had the form of regular crystals the gold content was segregated in the midst of them as a single grain. When, however, the original pyrite was present as irregular grains, the gold originally distributed uniformly throughout its mass was unable, during the alteration of the pyrite, to reach the center of that space from all sides, and the gold gathered in grains at two or three convenient points. That a part of the gold passes into solution during the decomposition of the ores is proved by the fact that this metal occurs in the mine waters of Australian gold mines. (The real solvent may be a chloride present in small amount in a solution containing $Fe_2(SO_4)_3$. As shown by H. N. Stokes, $Fe_2(SO_4)_3$ dissolves no appreciable amount of gold at 200° C. unless chlorides are present at the same time.)

The gold enrichment of the gossan has already been discussed. If, in the normal vein, native arsenic, arsenious pyrite or other arsenious ores are present, arsenious salts are formed in the gossan, namely arsenolite in the presence of calcareous waters, pharmacolite (hydrated calcium arseniate) frequently also pitticite or iron arsenide sinter, a porodine product at first of syrupy viscosity. The orpiment and realgar of Oravicza in the Banat, and of Allchar in Macedonia, may also be secondary minerals of the gossan.

[1] W. Mietzschke: 'Ueber das Verhalten des Goldes in Pyriten bei deren Verwitterung,' *Berg u. Hutten. Zeit.*, 1896, p. 193.

Smaltite ($CoAs_2$) and other cobalt ores give rise to an efflorescence of erythrite (hydrated cobalt arseniate) occurring in particularly fine crystal groups at Schneeberg in the Erzgebirge.

Nickel ores such as chloanthite ($NiAs_2$) oxidize to annabergite (hydrated nickel arseniate). In this alteration some free arsenious acid will always be formed, which acting on the gangue of brownspar and calcite will cause the precipitation of pharmacolite, haidingerite ($HCaAsO_4$, H_2O), wapplerite ($2H$ [Ca, Mg] AsO_4, $7H_2O$) and roselite, a similar compound of hydrated arseniate of cobalt. In the same way, in the presence of zinc, copper or iron minerals, hydrated arseniates of zinc, copper and iron are formed, or, as shown by Sjögren, if manganese is present, a multitude of the hydrated manganese arseniates are formed[1].

If the original deposit contains stibnite or other antimonious ores, the gossan will show kermesite, senarmontite, more frequently valentinite, stibiconite and cervantite, some native sulphur being usually precipitated at the same time. In the presence of lead ores, lead antimoniates may also be formed, as in several lodes in Chile.

II. New Substances Developed by the Chlorine, Bromine and Iodine Compounds of the Seepage Water.

The frequent presence of small amounts of chlorides in most of the waters circulating at shallow depths in the earth gives rise to chemical changes in the gossan of silver veins and the formation of horn silver (silver chloride = cerargyrite). The process may be represented by the following formula:

$$Ag_2SO_4 + 2Na\,Cl = 2Ag\,Cl + Na_2SO_4.$$

This is all the more likely because, according to G. Bischof[2], some of the analyses of cerargyrite indicate the presence of some sulphuric acid. The real starting point may be represented by argentite and other rich sulphidic silver ores, native silver, silver-bearing galenites, etc. Artificial products also may furnish cerargyrite. G. Bischof mentions old reports according to which silver coins from sunken ships were coated with a crust of silver chloride, and he cites Pallas, who in the saline soil of Siberia found old Tartar silver coins coated with cerargyrite. According to A. Schertel[3], Roman vases of silver obtained in the Hildesheim find of 1868 showed an outer crust of silver chloride (AgCl), above a layer of silver semichloride

[1] G. Brauns: 'Chem. Mineralogie,' 1896, p. 370.

[2] G. Bischof: 'Geologie,' 1866, Vol. III, p. 808.

[3] A. Schertel: 'Chemische Veränderungen am Hildesheimer Silberfunde,' *Jour. f. Prak. Chemie.*, 1871, Vol. 3, p. 317.

(Ag_2Cl). Between the latter and the unattacked metal, gold particles had concentrated, since the silver of the vases contained 2.7% gold.

Since native silver is so frequently found alongside of cerargyrite in nature, it is possible that the former has often been formed from the latter.

Cerargyrite sometimes appears in the form of concretions, or grains which may be detached from their genetic connections. Thus in the Apollyon Valley, and at Turnamoota in the Barrier range of New South Wales, on the surface near the outcrop of silver veins, concretions of this kind were found weighing several pounds, and containing, according to C. Watt, 72.23% of silver chloride.

In the presence of alkaline iodides and bromides in the seepage water, iodite (AgI), embolite (AgClBr), and the rarer bromite, are formed in the gossan. All these haloid compounds of silver, as well as native silver, have occasionally journeyed downward through the gossan and concentrated below. Thus at Broken Hill, within the gossan, whose upper part was quite barren, the famous horizons of immensely rich secondary silver ore were found only at a depth of 100 ft. (30 m.) In like manner the free milling argentiferous *pacos* ores of the Bolivian deposits only occur in the deeper zones of the gossan immediately above the sulphides.

According to F. A. Moesta[1] the Chilean silver veins show a succession of hornsilver ores in the gossan. The silver chloride is at the top, iodo-chloro-bromide of silver below, and still lower the pure silver iodide; below the chloride zone native silver, as well as argentite, polybasite and proustite, occur.

A similar explanation may be given for the occurrence of several other chemically related compounds in the uppermost parts of veins, viz.: atacamite ($CuCl_2$, $3CuO_2H_2$), calomel (HgCl), phosgenite ($Pb_2Cl_2CO_3$), as well as percylite (PbCl[OH].CuCl[OH]), and others.

In certain cases it seems proven that such chlorine compounds may form under the direct action of sea water on outcropping ores. Thus for example, B. R. Brauns[2] mentions the formation of laurionite [PbCl(OH)] and fiedlerite (a lead oxychloride of complicated compositions) through the action of sea water on the lead slag of Laurion, which is 2,000 years old. Moesta[3] even goes so far as to affirm that the rich cerargyrite of the Chañarcillo and other Chilean deposits was produced by the salt of sea water, which, according to him, stood at one time above the outcrops. Other authors have expressed similar views concerning hornsilver deposits, or

[1] F. A. Moesta: 'Ueber das Vorkommen der Chlor.- Brom- und Jodverb. des Silbers,' Marburg, 1870.

[2] R. Brauns: 'Chemische Mineralogie,' Leipzig, 1896, p. 367.

[3] *Op. cit.*

have at any rate assumed saline, marine sediments from earlier times in the vicinity of such finds, or, like C. Ochsenius[1], inferred that the 'mother lye' flowing out of upraised saline lagoons penetrated into the ore deposit from above. In individual cases this explanation may be appropriate. F. Sandberger[2] tried to support this hypothesis, especially by reference to hauntajayite (AgCl+20NaCl) which was found in the San Simon mine in the Cerro de Huantajaya in Peru, associated with silver chloride, silver chlorobromide, and atacamite.

On the other hand, it must be pointed out that considerable quantities of cerargyrite have also been found occasionally in the rocks of central Germany. At Annaberg, in the Erzgebirge of Saxony, for instance, in the 16th century, cerargyrite was found in the Himmlisch Heer mine in masses so large, pure and soft that figures are said to have been carved from it, since it could be cut 'like soap.' According to documentary evidence pure samples of it, alleged to have weighed fifty pounds, were furnished to the Natural History Cabinet of Dresden[3]. Cerargyrite in compact bodies was found on the Segen Gottes vein at Gersdorf as late as 1854, and about twenty-five years ago in the works of the Sanct Georg mine at Schneeberg, once so rich in silver, but flooded since 1550. At Gottes Geschick on the Graul, near Schwartzenberg, embolite occurred, though only rarely[4]. Now, as in the Erzgebirge it is not possible to imagine either an overflow by the sea, or a seepage of a residual lye from evaporated brines, it seems to us that with the exception of perhaps a few individual cases the theory above set forth is inapplicable to the other cerargyrite occurrences. If a rule may be formulated, as seems to be possible, it is that the drier a country is, the greater will be the amount of cerargyrite in the gossan of the veins. It is probable that the haloid compounds, formed in very small amounts by the weathering of rocks, were concentrated in the upper strata of the soil solely as a result of the hot climate and the enclosed condition of those regions. The blowing of saline dust by the wind, away from the coast or from saline lakes, may co-operate to produce this effect. The fact that in this process the metallic iodine and bromide compounds, which otherwise are relatively so much rarer, occur in considerable quantity alongside of the chloride minerals, has been appropriately explained by B. Kosmann[5] as a result of the greater insolubility of the former. The smaller quantities of alkaline

[1] C. Ochsenius: 'Die Bildung des Natronsalpeters aus Mutterlaugensalzen,' Stuttgart, 1887, p. 51.

[2] *N. Jahrb. f. Min.*, 1874, p. 174.

[3] H. Müller: 'Das Annaberger Bergrevier,' Leipzig, 1894, p. 92. A. Frenzel: 'Mineral. Lexikon für das Königreich Sachsen,' Leipzig, 1874, p. 167.

[4] M. Websky: 'Silberhornerz im Sct. Georgs Schacht zu Schneeberg,' *Z.* d. D. G. G., 1881, Vol. XXXIII, p. 703.

[5] B. Kosmann: 'Ueber die Bildung haloïdischer Erze.,' Leopoldina, XXX, 1894, p. 1.

iodides and bromides in the seepage water were always the first to combine as metallic haloids by the reaction with the ore minerals; the alkaline chlorides were then formed in turn. The succession of the cerargyrite zones, as cited above, after Moesta, does not, it is true, harmonize with this view.

A thorough investigation of the question of the origin of cerargyrite, taking into account both geological and chemical facts, is certainly a problem of very great scientific interest that still awaits a solution.

For the alterations and migrations of material in the gossan of gold veins, the presence of chlorine compounds in the seepage water has much significance. Since sulphuric acid is formed by the decomposition of the pyrites, as already shown, and since, moreover, psilomelane is common in the gossan formations, favorable conditions prevail for the development of chlorine as the most active solvent of gold. The gold may be precipitated again by undecomposed pyrites, which may lead to the development of zones especially rich in gold between the oxide and sulphide zones of the veins. Percy demonstrated the possibility of these processes by experiments[1].

III. New Compounds Formed by Combination with Phosphoric Acid.

The real source of the phosphoric acid in the gossan is probably in most cases the apatite of the country rock. When leached by water containing CO_2 it yields a solution of $Ca_3(PO_4)_2$, which decomposes on encountering gypsum and precipitates the metallic phosphates in question. The phosphoric acid in the solutions may also arise from decaying animal substances. In both cases pyromorphite, liebenthenite, phospho-chalcite, hopëite, cacoxenite, strengite, dufrenite and beraunite may be formed in the gossan.

IV. New Minerals Formed by the Liberation of Silicic Acid.

The decomposition of the feldspars of the country rock, by sericitization and other similar processes, sets free silicic acid, which may be reprecipitated as quartz, chalcedony, hornstone or opal, or may form compounds with the metals. A mineral especially common in the gossan of copper-bearing lodes is chrysocalla ($CuSiO_3$, $2H_2O$), and silicate of zinc frequently occurs in many zinc-blende deposits. Blue allophane ($Al_2SiO_5+Cu_2O+H_2O$) is rarer; it occurs in the Blaue Stolln at Zuckmantel in Silesia, being derived from the decomposition of copper-bearing pyrites. Ore deposits often hold included fragments of country rock rich in feldspar. In the gossan these

[1] T. A. Rickard: 'Formation of Bonanzas in the Upper Portions of Gold Veins,' *Trans.* Am. Inst. Min. Eng., February, 1901.

are often completely altered to kaolin, which may be strongly impregnated with silver chloride, as at Broken Hill.

V. Removal of Dissolved Substances.

Strong proof that all of the above mentioned decomposition processes prevail generally in the weathered outcrops of mineral veins, and that a very large part of the new compounds thus formed are not precipitated in the gossan, but are carried off in aqueous solution, is furnished by the analyses of mine waters[1].

I. The following analysis (a) by A. Frenzel represents a mine water of the Rothschönberger Stolln, near Freiberg, which gushed forth in 1877 from the Komm Sieg mit Freunden Spatgang; (b) is a second mine water from the same locality which gushed forth from the Hilfe des Herrn Stehende Gang; (c) is a third mine water in the same mine which also gushed forth from a vein.

The waters in question contained per liter:

	a.	b.	c.	
Sulphuric acid	0.2334	0.2224	0.2159	gram.
Silicic acid	0.0088	0.0080	0.0021	"
Alumina	0.0028	0.0007	0.0028	"
Ferric oxide	0.0067	0.0090	0.0068	"
Manganic oxide	0.0027	0.0059	0.0083	"
Zinc oxide	0.0235	0.0059	0.0035	"
Cobalt and nickel oxide	Trace.	Trace.	Trace.	
Chlorine	Trace.	Trace.	Trace.	
Lime	0.1485	0.1014	0.1270	"
Magnesia	0.0284	0.0247	0.0217	"
Insoluble residue	0.0175	0.0158	0.0210	"
	0.4723	0.3938	0.491	"

II. Chemical composition of the mine water of the Rothschönberger Stolln at its point of discharge in the Triebisch Valley. The average discharge is 500 liters per second. Analyses made by A. Frenzel in 1883. One liter contained:

Lime	65.0	milligrams.
Magnesia	24.9	"
Ferrous oxide	9.5	"
Zinc oxide	11.1	"
Chlorine	12.4	"
Silicic acid	18.0	"
Sulphuric acid	104.0	"
Total	249.9	"

From that it is seen that the amount of zinc oxide which is carried off by this water from the Freiberg mines averages 479 kilograms a day, or in a year 175,024 kilograms.

[1] H. Müller: 'Beiträge zur Kenntniss der Mineralquellen und Stollenwässe Freiberger Gruben,' *Jahrb.* f. d. B. u. H. im Königr. Sachsen, 1885.

In renovating the old workings of the Beihilfe Erbstolln on the Halsbrücker Spatgang, which had been flooded for 135 years, the walls of the levels and other workings were found to be covered with a black efflorescent coating one centimeter thick. An analysis of this crust made by H. Schulze showed it to have the following composition:

Manganese peroxide	44.78 per cent.
Oxygen	8.43 "
Ferrous oxide	7.78 "
Cobalt oxide	1.36 "
Zinc oxide	6.08 "
Cadmium oxide	0.19 "
Lead oxide	3.45 "
Copper oxide	3.20 "
Sulphuric acid	0.82 "
Water	19.84 "
Residue insoluble in acids	3.55 "
Total	99.48 "

The insoluble residue consisted of mica scales and quartz splinters from the country rock, the usual Freiberg gneiss.

The manner in which gold passes into solution during the decomposition processes forming the gossan is discussed on page 372 and also in the section on gold placers.

The Zone of Enrichment by Rich Secondary Sulphides.

Weed discriminates the following zones in ore deposits[1]:

(1) The zone of weathering; a zone above groundwater level, made up principally of oxides, carbonates, chlorides, etc., which may also carry rich secondary sulphides;

(2) The zone of enrichment; a transition zone at and below groundwater level, characterized by rich sulphides of silver, copper, lead and zinc, containing only subordinate oxidic ores;

(3) The zone of unaltered ores; the normal unaltered sulphides.

The poorer sulphides of (3) are altered to rich sulphides of (2) by reactions with the oxidic compounds contributed from above in solution.

These reactions may be of very diverse nature.

The following equations[2] indicate the nature of the chemical changes possible when copper sulphates come into contact with pyrite:

[1] The translator has replaced the original text by new material, assuming responsibility therefor.

[2] This synopsis of the chemical reactions involved in secondary enrichment has been kindly written by Dr. E. S. Sullivan, of the Chemical Laboratory of the U. S. Geological Survey. The equations are actual, not theoretical ones. W. H. W.

(1) Direct precipitation of sulphides:

(a) $CuSO_4 + H_2S = CuS + H_2SO_4$.
(b) $Cu_2SO_4 + H_2S = Cu_2S + H_2SO_4$.

(2) Reduction of Cu · · to Cu · by H_2S:

(c) $2\,Cu_2SO_4 + 2\,H_2S = Cu_2S + S + H_2SO_4$[1].

The sulphur may be further oxidized to H_2SO_4 with reduction of a greater amount of Cu · · :

(d) $6\,CuSO_4 + S + 4\,H_2O = 3\,Cu_2SO_4 + H_2SO_4$[2].

(3) Reduction of Fe · · · by Cu · :

(e) $Fe_2(SO_4)_3 + Cu_2SO_4 = 2\,FeSO_4 + 2\,CuSO_4$[3].

This reaction is reversed on heating to about 200°C.

(f) $2\,FeSO_4 + 2\,CuSO_4 = Cu_2SO_4 + Fe_2(SO_4)_3$[4].

(4) Splitting up of cuprous compounds into cupric and metallic copper:

(g) $Cu_2SO_4 = Cu + CuSO_4$[5]

The sulphur of metallic sulphides, as Fe_2S_3, is in the same form of combination (the same ion, S″) as in hydrogen sulphide, and in many respects behaves similarly. Polysulphide sulphur is, as a rule, loosely combined, and may be expected to act like free sulphur. Pyrite being regarded as ferric polysulphide, $Fe_2S_3S\,(=_2FeS_2)$, to represent its behavior in the above reactions Fe_2S_3 is substituted for H_2S, and the residual S for free sulphur, ferric or ferrous sulphate becoming an additional product.

In equation (a) for instance:

(h) $3\,CuSO_4 + Fe_2S_3S = 3\,CuS + Fe_2(SO_4)_3 + S$.

The ferric sulphate would be easily reduced by H_2S or S, the sulphur becoming free sulphur or sulphuric acid.

(i) $Fe_2(SO_4)_3 + H_2S = 2\,FeSO_4 + S + H_2SO_4$.
(k) $3\,Fe_2(SO_4)_3 + S + 4\,H_2O = 6\,FeSO_4 + 4\,H_2SO_4$[6].

This is sufficient to indicate also the behavior of pyrite in reactions (b), (c) and (d), the products being the same as in those equations with addition of ferric or ferrous sulphate.

Chalcopyrite, $Cu_2S,Fe_2S_3\,(=2\,CuFeS_2)$, and bornite, $3\,Cu_2S,Fe_2S_3\,(=2\,Cu_3FeS_3)$, combinations of cuprous sulphide and ferric sulphide, would, on entering into reaction, behave similarly.

[1] Branner: *Chem. News*, 1896, LXXIV, p. 99. Also *Compt. rend.*, 1884, XCVIII, p. 1492.

[2] Stokes: 'Pyrite and Marcasite,' *Bull.* No. 186, U. S. Geol. Survey, 1901, p. 44.

[3] Prescott and Johnson: 'Qualitative Analysis,' p. 159.

[4] Stokes, *op. cit.*

[5] Luther: *Zeit. phys. Chem.*, 1901, XXXVI, p. 392.

[6] 'Gmelin-Kraut,' Vol. 1, pt. 2, p. 219.

We have thus the possibility of a variety of changes, many of them conflicting. Which would preponderate, and what the final products would be where several are in simultaneous operation, depends on relative concentration, on temperature, and even on the pressure under which the substances find themselves[1]. One case involving a number of these reactions has been worked out, with careful control of physical conditions, by Dr. H. N. Stokes, as follows.[2]

"Copper sulphate acts in part according to the following equation: $5\ FeS_2+14\ CuSO_4+12\ H_2O=7\ Cu_2S+5\ FeSO_4+9\ H_2SO_4+3\ H_2SO_4$, the last H_2SO_4 being formed by oxidation of the sulphur of the FeS_2. The formation of H_2SO_4 was proved by quantitative analysis, both at 100 and 180°. The reaction is not as simple as thus expressed, for some CuS is formed less at 100 than at 180°. Cuprous sulphate, Cu_2SO_4, also plays a part in the reaction."

Lead salts are transposed into the least soluble of the lead compounds, galenite, by the sulphides of other metals, especially by those sulphides, such as blende, more soluble in water than galenite:

$$PbSO_4+FeS=PbS+FeSO_4.$$
$$PbCO_3+FeS=PbS+FeCO_3.$$

or,

$$PbSO_4+ZnS=PbS+ZnSO_4.$$
$$PbCO_3+ZnS=PbS+ZnCO_3.$$

Pyrite (Fe_2S_3S) might be expected to act similarly, its residual sulphur being deposited as such or oxidized, perhaps by Fe''' to H_2SO_4. Zinc sulphide may be formed thus:

$$ZnSO_4+H_2S=ZnS+H_2SO_4.$$

The action of pyrite on zinc compounds in alkaline solution was investigated quantitatively by Stokes, and found to result in ZnS, as follows:

$$14\ ZnCO_3+8\ FeS_2+NaCO_3=14\ ZnS+4\ Fe_2O_3+Na_2S_2O_3+15\ CO_2.$$[3]

Thus a regeneration of the galenite decomposed in the uppermost lode regions has been effected at a somewhat greater depth by the descending currents.

A deposition of secondary chalcopyrite, or, under certain circumstances, a first segregation of rich copper sulphides, may be caused in deposits of

[1] Any attempt to sum up such reactions in one chemical equation takes upon itself to decide which one or more of several conflicting changes will take place to the complete or partial exclusion of the others; this is not justified unless the facts in the case have been ascertained by quantitative analysis of the products formed, and even then such an equation is but an approximate representation of what actually takes place.

[2] MS. H. N. Stokes.

[3] MS. H. N. Stokes.

primary cupriferous pyrite by solutions of $CuSO_4$ entering from above, and may be expressed as follows:

Formation of Chalcopyrite and Bornite.

(1) Reduction of $CuSO_4$ to Cu_2SO_4 by sulphur of FeS_2.
(2) Transposition of Cu_2SO_4 to Cu_2S by Fe_2S_3.
(3) Union of Cu_2S and Fe_2S_3.
Incidental products: H_2SO_4; $Fe_2(SO_4)_3$; $Fe^{\cdots}$ reduced by S to $Fe^{\cdot\cdot}$, sulphur oxidized to H_2SO_4.

Cu_2SO_4 decomposes in part into Cu and $CuSO_4$, accounting for Cu associated with bornite and chalcocite.

Chalcocite may also be produced in various ways within the descending currents: Through the reaction of copper sulphates on pyrite:

$$14\ CuSO_4 + 5\ FeS_2 + 12\ H_2O = 7\ Cu_2S + 5\ FeSO_4 + 9H_2\ SO_4 + 3H_2SO_4.$$

This last H_2SO_4 is formed by oxidation of the sulphur of the FeS_2.[1]

Through the reaction of copper sulphates on chalcopyrite or bornite, a combination of such changes as those expressed in equations h, d, and b preceding.

As examples of these alterations we refer to the chalcopyrite nodules of the Monte Catini mentioned on page 48, with their envelope of bornite and chalcocite, associated with native copper. Also the cupriferous portions of the lodes of Butte near ground-water level, as well as the concentration of rich copper sulphides from copper-bearing pyrites in certain deposits in Arizona.[2]

In similar manner, in veins carrying slightly argentiferous sulphides, the silver salts formed by weathering may migrate downward, and the silver be precipitated at a lower level by contact with undecomposed sulphides of the veins as rich silver sulphides.

The reaction is as follows:

$$Cu_2S + 2\ Ag_2SO_4 = Ag_2S + 2\ Ag + 2\ CuSO_4.^3$$

This reaction explains the frequent association of native silver and argentite in mines.

$$Cu_2S + 4\ AgCl = Ag_2S + 2Ag + 2CuCl_2.$$

The principle of secondary enrichment of copper ores has long been known and was definitely formulated by Emmons[4] in 1897, while a general application of this principle to gold, silver and other metallic deposits was

[1] MS. of H. N. Stokes: See note on the equation on previous page.

[2] R. A. Penrose: 'The Superficial Alteration of Ore-Deposits.' *Journ. of Geol.*, II, 1894, pp. 306–308. Jas. Douglas: 'The Copper Queen Mine, Arizona,' *Trans.* Am. Inst. Min. Eng., February, 1899.

[3] Schneider: *Pogg Annal.*, 1874, Vol. CLII, p. 471.

[4] U. S. Geol. Survey, Folio 39, Butte, Mont.

given by Weed in 1898[1] and 1899[2], and independently by Emmons[3] and Van Hise[4] in 1900. The latter had long since explained the formation of the Lake Superior iron ores as being due to a similar process. (W. H. W.)

L. De Launay studied the processes of weathering in detail and emphasizes the removal of the more readily soluble substances. He did not, however, recognize any changes below water level or the reactions between descending solutions and primary sulphides.

The formation of rich secondary sulphide ores by reactions between primary ore and later uprising deep waters, according to the theory of W. H. Weed, is not a gossan phenomenon and is discussed elsewhere.

The expression, "zone of rich sulphides," must not be understood in the sense of a definite, sharply defined zone. Lesser and later fissures permit a descent of the seepage water from above to the deeper portions of the deposit, with accompanying leaching in some parts and enrichment in others.

The Distribution of Ore Within the Veins.

Only very rarely do we find the ore minerals of a vein uniformly distributed through the vein filling. This filling consists chiefly of various gangue minerals, quartz, calcite, brownspar, rhodochrosite, fluorite, etc., as well as of fragments of the country rock. A rare case occurs at the rich Smuggler vein of Telluride, Colorado, in which for a distance of nearly three-quarters of a mile (1 km.) there was not a single spot that could not be profitably worked. As a rule the pay ore is concentrated in parts of the vein known as bonanzas, pay streaks, shoots, pipes, chambers, bunches, and nests, as the workable portions are variously called. The poor or lean portions are known simply as barren places, or have received no distinctive name[5].

The determination of the form and distribution of the orebodies of a vein, horizontally and vertically, and the relations between these occurrences and the general and structural geologic conditions of the vein and its enclosing rocks is not only of great practical value, but also of the highest

[1] 'Secondary Enrichment of Veins, Geol. of Little Belt Mts.' 20th *Ann. Rep.* U. S. Geol. Survey, 1898–9, p. 412. 'Kemp Ore Deposits,' p. 38.

[2] 'Geol. Society America Program and Abstracts of Papers,' November, 1899, *Science*, November 20, 1899. 'Enrichment of Mineral Veins by Later Metallic Sulphides,' *The Engineering and Mining Journal*, December 30, 1899. *Bull.* Geo. Soc. Am., 1900, Vol. II, pp. 179–206.

[3] W. H. Weed: 'Enrichment of Gold and Silver Veins.' 'Genesis of Ore Deposits,' p. 473. S. F. Emmons: *Idem*, p. 433.

[4] C. H. Van Hise: *Idem*, p. 282.

[5] When pay ore occurs the vein is said to be rich; the transition from a barren to a rich portion is called enrichment (Veredelung), and conversely the passage from a rich to a barren region is called impoverishment (Vertaubung).

scientific interest. For a long time the investigators of ore deposits have endeavored to discover, if possible, general laws governing the distribution of the orebodies in veins, laws which might in turn prove useful in mining practice. However, the results thus far obtained have only a local application. In the following sections, pp. 382 to 395, some general causes of the origin of rich orebodies will be discussed.

The unequal distribution of orebodies appears best in a well executed longitudinal section along the vein, that is to say, a section parallel to the strike and dip. This should show the shafts, horizontal drifts, and the actually developed and worked portions of the veins, besides the intersections of other veins, and if possible the changes in the nature of the country rock. Compare Figures 187 and 188.

A very frequent phenomenon is the presence of orebodies dipping diagonally across the vein, the so-called pitching ore shoots (Erzfalle or Adelvorschube) (see for example Fig. 175); these narrow orebodies, whose longer diameter coincides with the line of dip, the so-called ore pipes, are especially common in gold veins[1] (see, for example, Fig. 181), while the bunches are masses which have a very limited extent.

The word, "Adelvorschube" (ore shoot), was first used only in the mines of the Heinzenberg and Kelinkogl, and was introduced in science by J. Trinker[2]. In the Kleinkogl deposits in northern Tyrol, containing copper and silver ores, he proved that the different bonanzas of the successive lodes follow one another in accordance with a certain law, all being inclined at about 30° to the horizon in the direction from south to north. This behavior he calls a general enrichment (Generellen Adelsvorschube).

In America Clayton's law has proven locally applicable in many mineral districts in the western United States. According to this the ore shoots pitch to the right in looking down a lode along its dip. The detailed studies by Lindgren and others fail to confirm the general application of this.

The word 'bonanza' is much used for rich orebodies, especially in silver mines. In Mexico it means merely payable ore; in common usage it means a body of very rich ore. The bonanzas of the Comstock Lode are especially famous.

For the most part the workable orebodies represent only a small part of the entire lode. Thus Freiherr von Beust, in 1859, estimated the pay streak to constitute 20% of the area of the vein in longitudinal section of the workable Freiberg lodes. Later statistics (1871) gave only 15 per cent.

[1] E. Skewes: 'The Ore-Shoots of Cripple Creek.' *Trans.* Amer. Inst. Min. Eng., 1897, XXVI, p. 553 *et seq.*

[2] J. Trinker: 'Der Adelsvorschub am Heinzenberge und am Kleinkogl.' *Jahrb.* d. k. k. geol. Reichsanst., 1850, Vol. I, p. 213 *et seq.*

Different conditions obtain when the enrichments of lodes are due not to a higher grade of ore, but to an increased amount of ore, in consequence of a widening of the lode fissure. We may refer to what has been said on page 148. In this sense, in the veins which are fault fissures, those sections would always be the richest in which there is a great variation of dip, because in such cases the displacement of the walls develops the largest lode spaces. This idea was advanced in somewhat similar terms by W. J. Henwood[1].

In the case of a well-banded vein filling, much will depend on whether the richest crusts are the latest or the youngest. If they are the youngest they will often be met only at points where the lode is greatly expanded, whereas, they will be commonly absent where it is much contracted.

Influence of the Country Rock on the Richness of Lodes.

For several centuries the German miners have been acquainted with the undeniable influence of the country rock on the ore content of mineral veins. They spoke of an "obliging, mannerly rock" (einen artigen, hefflichen Gebirge), as compared with a "wild and unfavorable" (wilden und unartigen). The first detailed scientific investigation upon this subject was begun by the Freiberg geologists, H. Müller and B. von Cotta. We will first note a number of examples in which a different country rock is accompanied by a difference in ore, and afterward discuss the real causes of this phenomenon, so far as known.

A very detailed study of this subject, applied to the Freiberg area, was published by H. Müller[2] as early as 1850, from which we extract the following:

The most striking fact in the Freiberg lodes is the unfavorable influence of the mica schist as compared to the favorable influence of the gneiss. This is all the more unpleasantly conspicuous because the very richest, highest grade veins of the district occur where such mica schist intercalations occur within the gneiss, so that the workable ore is restricted to a limited part of the field. The most important veins of the north of the town furnish numerous illustrations. Thus the great bonanza of the Peter Stehende vein ends northward where the vein passes from gneiss into mica schist, and the rich vein filling of the Wilhelm Morgengang and the Friedrich Flache veins of the same locality changes to barren gangue in the mica schist.

The veins of Alte Hoffung Gottes also run southwestward into mica

[1] W. J. Henwood: 'Metalliferous Deposits of Cornwall and Devon.' *Trans.* Roy. Geol. Soc. of Cornwall, V.

[2] H. Müller: 'Erzlagerstätten bei Freiberg.' Cotta's Gangstudien, 1850, Vol. I, pp. 209–248.

schist. While in the gneiss they are 0.6 to 2.2 feet (0.2 to 0.8 m.) thick, and consist of quartz, brownspar and rhodochrosite, containing pyrite, sphalerite, galena and, not infrequently, rich silver ores. In the mica schist these veins narrow to a thickness of a few inches, the gangue and ore

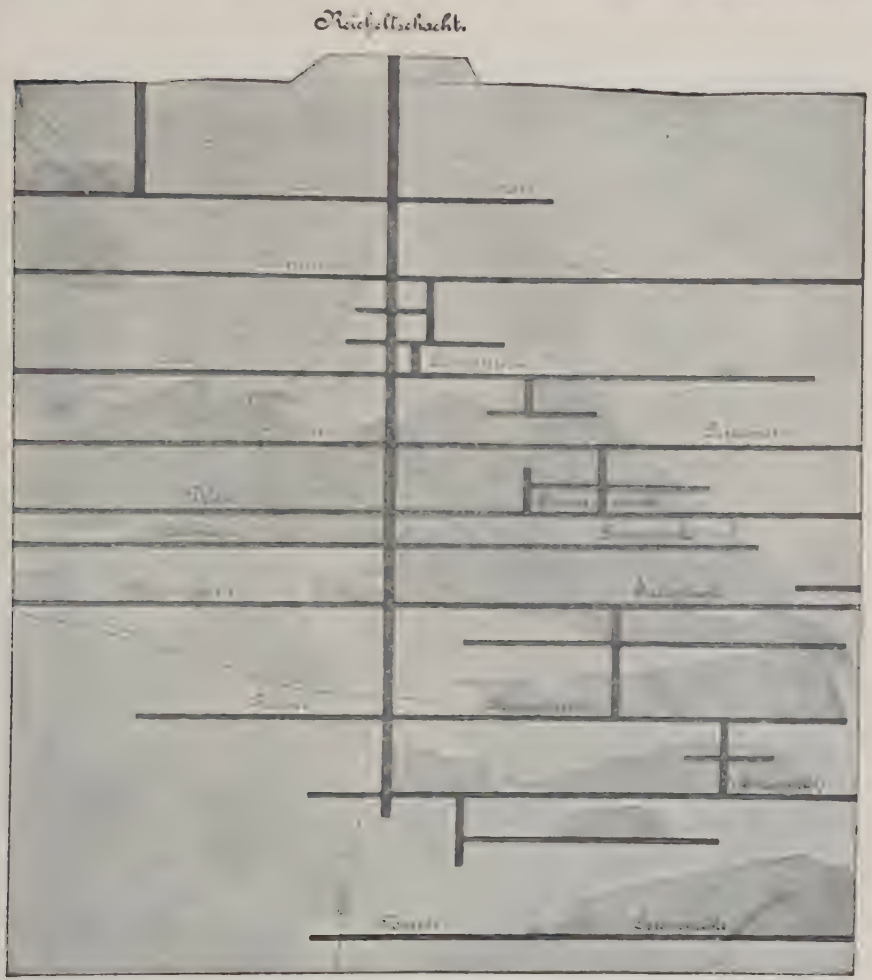


Fig. 187.—Horizontal section of the Jupiter vein in Himmelsfurst mine. (Plate of the Royal Mining Bureau.)

minerals are lacking, and the filling consists almost solely of decomposed fragments of the country rock, friction breccia and gouge.

The same phenomena is repeated in the Himmelsfürst mine at Brand in the rich lead veins (carbonspathic lead formation). As is shown distinctly

by the accompanying section through the Reichelt shaft of the Jupiter Stehende (Fig. 187), prepared from the official mine maps, the rich ore streaks are found in the so-called Himmelsfürst gneiss, a normal biotite gneiss underlying the mica schists. In the mica schist the veins grow so poor that no excavations are recorded. A similar distribution of ore is found in several other lodes of this district. On the other side of the bands of mica schist, rich ores again appear in some veins, as, for example, in the Wiedergefunden Glück Stehende. In the mica schist itself, however, pay streaks were found along the intersections with other veins, as, for example, in the Lade des Bundes Flachen, along the intersection with the Johannes Stehende.

To explain these conditions in the Himmelsfürst mine the hypothesis of "an enrichment of the veins just before they pass into the mica schist, particularly along the lower gneiss-schist contact," is even more appropriate than the assumption "of an impoverishment of the ore lodes in the mica schist," since the value of the ore along the under wall of the mica schist far exceeds that usually found in the vein when encased in normal biotite gneiss.

The following statistics prove the great wealth of this zone: In the Silberfund Stehende, from 1857 to 1879, the ores from 47,366 square meters of lode surface, weighing 7,940 metric tons, gave an output of 4,426,784 marks ($1,107,192); in the Kalb Stehende the ores from 34,017 square meters lode surface, weighing 6,194 metric tons, gave 2,199,874 marks ($550,000), so that in the first case the square meter yielded on an average 93 marks, in the latter 65 marks.

To explain this "contact enrichment" (H. Müller), one must also consider the possibility of a checking or stagnation of the rising solutions caused by the imperfect fissuring of the mica schist.

A closely analogous phenomenon exists in silver-quartz veins, as shown by longitudinal sections of several lodes of the Segen Gottes Erbstolln at Gersdorf, near Rosswein, as well as in the Friedrich Flachen, of the barytic lead veins. In all these veins extensive orebodies occur where the veins are in the gabbro and granulite. The orebodies attain their greatest thickness and value at the immediate contact plane between the phyllite (mica clay slate) and the gabbro and granulite faulted against it; the ore stops where the veins pass into the phyllite hanging-wall.[1]

We may mention a few examples from other regions of the influence of the country rock on veins. The number might be considerably increased from the old descriptions by B. von Cotta[2].

[1] H. Müller: 'Die Erzgänge des Freiberger Bergrevieres,' 1901, p. 296.

[2] B. von Cotta: 'Erzlagerstätten,' I, 2d ed., 1859, p. 133, *et seq.*

In the barite veins of Schweina and Kamsdorf, in the Thüringer Wald (see page 227), at Riechelsdorf, in Hesse, where the veins traverse the bituminous copper shales, they contain pay streaks of cobalt, nickel and copper ores, while in overlying beds of the Zechstein formation and in the rocks beneath the copper schist the veins are barren.

At Pribram the veins are profitable in the Cambrian quarzitic sandstone, but not in the clay slate adjoining on the northwest (see Fig. 158 and 159). This is, however, probably due more to the influence of the clay fissure mentioned on page 143 than to the clay slate in itself.

In Cumberland the lead veins, according to Dufrenoy[1] and others, traverse Carboniferous limestone, with interbedded sandstone and clay slate. While in the limestone the veins are thick and workable; in the sandstone and slate they break up into unprofitable stringers. Similar conditions are observed in Derbyshire, where the lodes become poor and divide into stringers as soon as they enter the intrusive sheets and dikes of diabase amygdaloid (locally called toadstone).

The influence of fahlbands of the schists upon the Kongsberg silver ore lodes has already been mentioned on page 275.

The copper lodes of Butte, Montana, according to W. H. Weed[2], are ore-bearing in the basic granite and are low grade or barren in the aplite.

An interesting example of the enrichment of gold-bearing lodes in passing through a particular rock occurs in the Ballarat gold field of Victoria, Australia[3]. The quartz veins traverse a series of steeply upturned Silurian slates, but only carry pay ore where they cross extremely thin but persistent beds (½ inch to 6 inches thick) of a heavily pyritized bituminous shale. These intersections are exceedingly rich in gold, and, in mining these, thin beds known as indicators are followed. The indicators themselves are barren[4]. See Fig. 187*a* and 187*b*.

It should, however, be noted that there are districts in which the distribution of the ore in veins is apparently independent of the character of the country rock. An exceptional case described by Wittelsbach[5] occurs in the Santa Elena and La Carolina mineral districts, near the Linares lead region. The Paleozoic slates and intruded granite masses are cut by

[1] Dufrenoy, E. de Beaumont, Coste and Perdonnet: 'Voyage métallurgique en Angleterre.' Paris, 1837 and 1839.

[2] W. H. Weed: 'Influence of Country Rock on Mineral Veins,' *Trans.* Am. Inst. Min. Eng., November, 1901.

[3] T. A. Rickard: 'The Indicator Vein, Ballarat, Australia.' *Trans.* Am. Inst. Min. Eng., August, 1900. With bibliography.

[4] See 'Characteristics of Gold Quartz Veins of Victoria,' W. Lindgren, *The Engineering and Mining Journal*, March 9, 1905. Also Weed, *op. cit.*

[5] A. O. Wittelsbach: 'Fragen und Anregungen,' etc. *Zeit. f. Prak. Geol.*, 1897, p. 5.

Fig. 187*a* —The Indicator. 500-ft. level No. 1, Llanberris mine. (T. A. Rickard.)

Fig. 187*b*.—The Indicator. Diagram, explaining Fig. 187*a*. (T. A. Rickard.)

argentiferous lead veins, with a quartz and barite gangue. Some of these veins, such as the Esperanza and the Gabriel, only carry ore when in the granite, becoming barren in the slate, while, on the contrary, others, such as El Castillo, are ore-bearing in the slate and barren in the granite; and yet El Castillo is only one kilometer distant from La Esperanza.

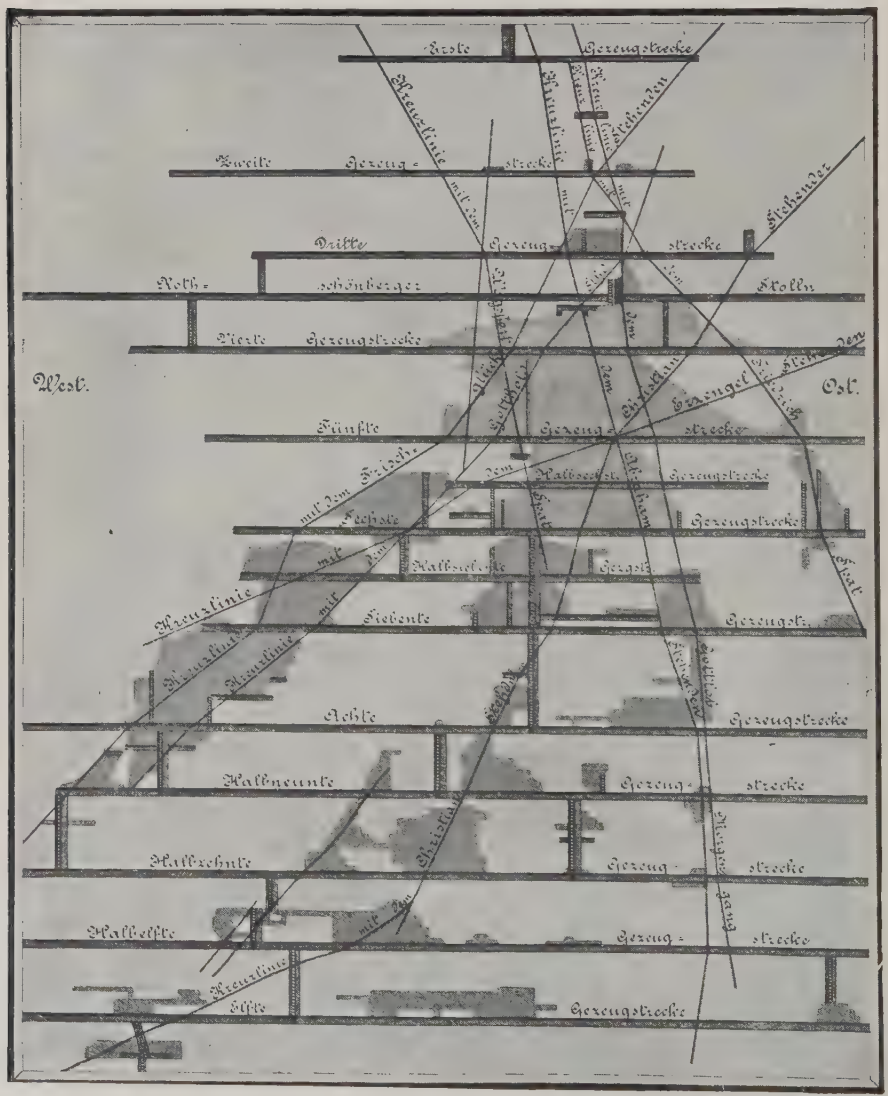


Fig. 188.—Longitudinal section along the vein of the Neu-Hoffnung Flachen at Himmelsfahrt at its crossing with several other lodes. (From plate of the Royal Mining Bureau.)

In some cases the influence of older upon younger veins is due to intersections in which the nature of the older vein filling influences the later ore deposition.

Influence of Vein Intersections on Ore Content.

The occurrence of rich ores and ore shoots at vein intersections in the lodes of the Freiberg district has long been known.

According to H. Müller, the enrichments occur both at intersections of two veins of similar mineralogic type and of those of different classes. This enrichment consists in an increased thickness of ore or of richer ore, or both these features. It is noteworthy that the rich silver ores, pyrargyrite and proustite, argentiferous tetrahedrite, argentite, polybasite and stephanite, as well as native silver, show a tendency to form at such points.

The enrichment is most marked when the veins intersect at acute angles, because the intersecting vein walls are close together and for longer distances. Hence dragging intersections, in which the angle of crossing is very small, are the richest; perhaps this is because the mass of crushed and permeable rock is much greater in acute than in obtuse or rectangular intersections.

The intersections of the lead barite Neu-Hoffnung Flachen vein with pyrite-blende-galena veins (Erzengel and Christian Stehende), of the Himmelsfahrt mine, near Freiberg, are especially famous (Fig. 188), yielding a million or more dollars. Masses of native silver weighing many hundred pounds were found there. The most noteworthy find was in 1858, when about 5,000 kilograms of silver were gotten out of the intersection between the Kalb Stehende and the August Flache. In three years $250,000 profit was made from the excavations at this intersection.

An impoverishment at vein crossings is very rare, according to H. Müller. The Abraham Morgeng vein, which is in itself an example, drags against a Spat vein for a distance of more than 105 feet (32 m.) and yet throughout that distance consists merely of gouge-filled fissure. Similar phenomena have become known from other lode areas.

Influence of Converging or Diverging Stringers on the Ore Content of Veins.

What has been said of vein crossing is also true in a lesser degree of vein stringers (splits or spurs), as shown by H. Müller[1] by numerous examples. Where two or more main stringers unite, many of the Freiberg lodes show a distinct enrichment, not only in quantity but also quality of ore, while conversely the diverging stringers grow poorer away from the main ledge and finally become completely barren.

[1] H. Müller: 'Erzgänge des Freiberger Bergrevieres,' 1901, pp. 297–304.

This phenomenon is repeated in many other regions. For example, F. Klockman says[1]: "The rule that the richest orebodies occur at the points where the lodes unite is verified throughout the vein area of the upper Harz."

The real cause of the enrichment of veins at intersections, and where stringers converge or diverge, may in part be due to a mixture of two chemically different solutions and the various reactions thence resulting. Such reactions might occur even when one lode had originally no metallic content, since in point of fact rich intersections with barren fissures are well known in certain lodes. If, on the contrary, one of the fissures already had a solid mineral filling, the causes fall within the scope of the second article after the next, since the pre-existing filling in this case figures merely as country rock.

In lodes of the same age the vein junctions present favorable conditions for ore deposition because the fissure spaces available for the deposition of ores might be wider and thus remain accessible to the circulating solutions for a longer time than elsewhere.

Influence of the Folding of a Stratified Country Rock on the Richness of Veins.

Where mineral veins cut through a folded system of strata the structural features of that system have sometimes exerted a manifest influence on the ore content. Thus, according to J. A. Church[2], at Tombstone, Arizona, the largest orebodies occur where the veins intersect the anticlines of Carboniferous limestones, quartzites and slates. Horizontal orebodies also occur in the form of epigenetic stocks along the anticlines, consisting in the main of gold-bearing silver-lead ores, the mineralization being confined to certain beds of limestone and quartzite. The fissures, however, carry ore at points where the slate of the anticlines forms the country rock.

Cause of the Influence of Country Rock on the Distribution of Ore[3].

Although from the preceding statements it appears that the distribution of ore in mineral veins is influenced by the nature of the country rock, yet

[1] F. Klockmann: 'Berg und Hüttenwesen des Oberharzes,' 1895, p. 48. Zirkler: 'Ueber die Gangverhältnisse der Grube Bergmannstrost bei Clausthal.' *Glückauf*, Essen, 1897, p. 93.

[2] 'The Tombstone, Arizona, Mining District,' *Trans.* Am. Inst. Min. Eng., May, 1902.

[3] C. Le Neve Foster: 'Ore and Stone Mining,' 1894, p. 12. W. H. Weed: 'Influence of Country Rock on Mineral Veins.' *Trans.* Am. Inst. Min. Eng., Vol. XXXII, November, 1901. 'Amer. Geol.,' 1902, Vol. XXX, p. 170.

both in individual cases and in general it is quite difficult to ascertain the true cause of this influence. It must be confessed that our knowledge of this subject has advanced but little since the time when B. von Cotta[1] wrote his 'Materialien zu Einer Theorie,' aside from the question of lateral secretion, to be treated connectedly later on.

Not only does the character of the fissuring vary in different rocks, which is a mechanical feature, but there is a variation in the amount and value of the ore, particularly the richer ore. While this latter feature is a chemical one, it is of great practical significance. The solution of these questions is, in the main, a purely chemical problem. The deposits in which the ore minerals of the vein filling have been derived from the country rock immediately adjoining the vein by leaching, a phenomena which, of course, involves a direct genetic connection between the two, will be described in a special section. But even if we admit that both the metallic and non-metallic minerals have been brought into the vein fissures from a distance and by ascending currents, there must be some chemical reaction between the vein-forming solutions and the minerals of the wall rocks and this must have some influence on the distribution of the minerals of the vein.

There is convincing proof that zones of very bituminous or carbonaceous rocks exercise a markedly favorable influence upon the contents of veins passing through them, and this is due to a reduction of the sulphates in solution by the carbonaceous material[2]. For other rocks it is not so easy to determine the exact nature of this relation. The replacement of the silicate minerals of a rock by ores as a result of a decomposition of these minerals by the vein-forming solutions was first discussed in detail by G. Bischof[3]. At Freiberg the evident relation between orebodies and the "normal Freiberg gneiss," a granular-fibrous mica schist or biotite gneiss, has been carefully investigated by several geologists. Special chemical investigations carried on by Th. Scheerer[4] led him to announce a theory for this relationship. This author started with the fact (demonstrated by H. Müller) that the biotite gneiss is a much more favorable wall rock for rich ores than the muscovite gneiss, and concluded that the biotite is the real cause of this favorable influence. He thought that the black mica, owing to its holding an excess of weak bases, especially ferrous oxide and manganese, offered far less resistance to the action of acids than the light col-

[1] B. von Cotta: 'Lehre von den Erzlagerstätten,' I, p. 148, *et seq.*

[2] W. P. Jenney. 'Chemistry of Ore Deposition,' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Bischof: v. Leonhard's *Jahrb.* f. Min., etc., 1844, pp. 257–341.

[4] Th. Scheerer: 'Die Gneuse des Sächs. Erzgebirges und verwandte Gesteinenach ihrer chemischen Constitution und geol. Bedeut.' *Z.* d. D. G. G., 1862, p. 23 *et seq.*

ored mica. Under this supposition Th. Scheerer imagines the process of lode filling to have taken place as follows:

Carbonated water containing hydrogen- or alkaline-sulphides leaches the deep zone of heated rocks and extracts SiO_2, CaO, BaO, metallic sulphides and compounds of arsenic and antimony, and carries its chemical burden into the upper parts of the fissures. There the precipitation and deposition of these substances takes place, partly through a diminution of pressure and temperature, and partly by a reaction between the solution and the biotite of the gneiss of the vein walls. The biotite is decomposed by the surplus CO_2, yielding $FeCO_3$ and $MgCO_3$, thus indirectly causing a decomposition of the earthy bicarbonates, which lose their solvent CO_2 and are deposited to form the carbon-spars so common in veins. Meantime the H_2S or the alkaline sulphides act on the newly formed iron carbonate, and pyrite is precipitated and, as the decomposition of the mica progresses, the other metallic compounds of the solution are finally precipitated. The foliated structure of the biotite, with its interlocking scales, is a condition particularly favorable to the lateral progression of this decomposition. The particles of metallic sulphides which occur disseminated through the decomposed gneiss on both sides of the veins also prove the precipitating influence of the biotite.

This theory has the disadvantage that it is not applicable to mineral veins of entirely similar composition in districts in which neither the brown mica nor a chemically similar mineral is present in the country rock. We reproduce Scheerer's explanation because this form of the hydro-thermal theory, to be discussed a little further on, has lately been resuscitated and expressed in closely similar terms.

The enriching influence of vein intersections has been often explained as due to electrolytic processes, and an analogous explanation has been applied to the influence of the fahlbands in Kongsberg.

Skey has shown that, for example, an element, consisting of a piece of kaolinite and a bit of pyrite immersed in sea water, is able to precipitate the metal from a solution of copper sulphate, and Chr. A. Münster[1] proved that samples of pyritic schist (fahlband) caused a precipitation of the silver from a solution of Ag_2CO_3. It is supposed that many instances where native silver occurs at vein crossings are susceptible of similar explanation.

That electric currents do sometimes exist in mineral veins was proved many years ago by Fox, Henwood, von Strombeck and Reich[2], and was

[1] Cited by P. Krusch: 'Kongsberger Erzrevier.' *Zeit. f. Prak. Geol.*, 1896, p. 101.

[2] F. Reich: 'Leitfaden zu den Vorlesungen über Physik.' Part II, 1853, p. 62.

confirmed anew by Barus[1] and Erhard[2]. Reich in Freiberg reached the following conclusions:

(1) Two particles of ore in a mine, separated from each other either by barren rock, or a cross vein, or an opening (natural or artificial), generate an electric current when connected by a metallic wire.

(2) Two particles of ore in constant contact with each other give no current when connected by a wire.

(3) Two samples of rock free from ore minerals give as a rule a current when there is ore near by.

(4) The electro-motive force producing the currents is always much smaller than one daniell (somewhat less than one volt).

Th. Erhard has described very convenient methods for investigations of this sort, but states that they are not of any practical use in hunting for new orebodies.

That the influence of the country rock on the mineralization of a vein may, however, be due to a combination of other factors, such as difference in conductivity of heat, porosity, smoothness or roughness of the rock surfaces, etc., has been set forth by B. von Cotta[3]. Direct proof in individual cases is still lacking.

The Action of Vein-Forming Solutions Upon the Wall Rock.

The influence of the vein-forming solution upon the walls of the fissure is quite apparent. In fact, the rock directly adjoining mineral veins rarely shows its original habit, having nearly always undergone some chemical or mineralogical change. Inasmuch as we shall later on, in discussing the various theories of vein genesis, give our support to the thermal theory, at least for the great majority of the mineral veins, we can, admitting the correctness of this theory, conceive these changes as rock alterations due mainly to rising thermal waters, and we shall accordingly speak of a hydro-thermal alteration[4] of the country rock, excluding in the discussion so far as possible the alterations in the upper parts of veins that result from later operations, or post-thermal influences.

In most cases the various chemical changes of the country rock have been preceded, and the rock prepared for ready alteration, by strong

[1] Barus: 'On the Electrical Activity of Ore-Bodies,' in G. F. Becker's 'Comstock Lode.' 2d *Ann. Rep.* U. S. Geol. Surv., 1882, pp. 320–324.

[2] Th. Erhard: 'Ueber die elektrischen Ströme auf Erzgängen.' *Jahrb.* f. d. Berg- u. Hüttenw. im K. Sachsen, 1885. pp. 1–15.

[3] B. von Cotta: 'Lehr von den Erzlagerstätten,' Vol. I, pp. 149-151.

[4] H. Rosenbusch: 'Studien im Gneissgebirge des Schwarzwaldes.' Heidelberg, 1899, p. 16.

mechanical forces, producing fissuring, distortion and crushing during the formation of the fissures.

This alteration is usually recognizable by a more or less pronounced bleaching or discoloration of the rock and a loss of hardness. This is the condition designated by the miner as "faul" (rot). In fact, the word gneiss (gneuss) is very probably due to this peculiarity, which must have been the first thing recognized by the miner, throughout the lodes of the Erzgebirge, when the first prospecting work was being done, the region being at that time half Slavic.

In Wendish *gnisch* means to rot and *gnoj* means manure, which words, according to Kalkowsky[1], are from the same root as gneuss. It had probably been long suspected that this bleaching of the rock along the vein fissures was due to the removal of the iron compounds and other chemical changes. This bleaching is especially striking when the country rock is originally dark or of brilliant color, as for example, the hornblende schist of Kongsberg, or at Freiberg, the quartz porphyry. The only accurate investigation of the subject is that made by Th. Scheerer[2], in Freiberg. From a comparison of a number of accurate analyses of both the fresh biotite gneiss and the decomposed country rock of the veins, he inferred that during the alteration the gneiss had first lost a considerable amount of silicic and titanic acid, and fully 15.2% out of the 18.8% of fixed bases contained in the normal gneiss as complex aluminous silicates. Among other things 96.5% of the total quantity of iron oxide had been withdrawn from the rock. The water content had risen from 1 to 2.5%. Furthermore, Scheerer's analyses proved an immigration of metallic sulphides into the decomposed gneiss, a fact manifest to the eye.

Similar investigations were soon after made by R. Pearce[3], later by von Groddeck[4] and recently by Stelzner, Lindgren[5] and others. The last named author has shown by his very careful work the importance of metasomatic processes in vein formation, and has classified veins according to the nature of the metasomatism. Sometimes mineral veins show evidences of two periods of dissimilar character. The rather complicated and in

[1] E. Kalkowsky: 'Die Gneissformation des Eulengebirges.' 1878, p. 14.

[2] Th Scheerer: 'Die Gneuse des sächs. Erzgeb.,' etc. *Z.* d. D. G. G., 1862, Vol. XIV, p. 89 *et seq.*

[3] R. Pearce: 'The Influence of Lodes on Rocks,' *Rep.* Miners Assoc. Cornwall, Truro, 1864, p. 18.

[4] A. v. Groddeck: 'Zur Kenntniss einiger Sericitgesteine, welche neben und in Erzlagerstätten auftreten.' *N. Jahrb.* f. Min., 1882, vol. II, pp. 72–138. Also 'Studien über Thonschiefer, Gangthonschiefer und Sericitschiefer.' *Jahrb.* d. Kgl. preuss. geol. Landesanst., 1885, pp. 1–52.

[5] W. Lindgren: 'Metasomatic Processes in Fissure-Veins.' *Trans.* Am. Inst. Min. Eng., February, 1900.

many ways interrelated phenomena are for convenience separated into classes. The first and the commonest is sericitization.

Sericitization.

A. von Groddeck, using a great number of bulk analyses, proved that clay shales, graywacke slate and similar rocks occurring alongside of or near mineral veins (fissure or bedded) are often changed into sericite-rocks, the original chloritic constituents being leached out and newer carbonates and quartz being formed. His work treated mainly of the rocks of the vein districts, Holzappel, Wellmich and Werlaw, where the altered country rock had long attracted attention and was known as 'Weisses Gebirge' (white rock). He also studied the so-called Lagerschiefer of Mitterberg, the white slates about the pyrite deposit of Agordo and the clay slates of the veins of the upper Harz.

In the slate fragments of the vein filling, which consist of completely crushed and ground Culm slates, Groddeck states that the chemical change is unmistakably due to the solutions forming the veins. In the black slates this chemical action shows in a progressive leaching out of the original ferric oxide and magnesia content, a process which has reached its completion in the variegated varieties. From numerous careful analyses he found the average composition to be as follows:

	Culm clay shales.	*Slate of Vein Filling.*	
		Black.	*Variegated.*
FeO	4.87 per cent.	1.06 per cent.	0.00 per cent.
MgO	1.80 "	1.11 "	0.00 "

From the chemical analyses and a microscopic investigation it was shown that the normal slates, of the Culm and Devonian formations of the upper Harz region, consist of quartz and sericite and a chloritic mineral, with small amounts of rutile, carbonaceous material and various carbonates. The analyses show that while in the black slate of the vein filling the percentage of quartz is almost unchanged, the amount of sericite, which is about 39% in the normal slate, has increased to 47%. In the variegated slates of the vein filling the silica has increased from 35 to 63%, with a corresponding decrease of the sericite to about 35%. These last named rocks consist of a mixture of quartz and sericite, with a little rutile and considerable specular iron. The chlorite has been completely removed.

At Freiberg, the investigations begun by Scheerer were continued by A. W. Stelzner with improved methods and much greater accuracy. This work demonstrated that alongside of the veins the gneiss is altered to a

clayey decomposition product in which the zircon and apatite remain quite fresh, while the chief minerals of the gneiss, viz., quartz, feldspar and mica, have been wholly or almost completely altered to potassium mica (sericite). This mineral occurs in minute scales of hexagonal or rounded outline and in small round aggregates, which form the bulk of the decomposed gneisses. This material, separated by Stelzner from the altered country rock adjoining the Dietrich Stehenden vein, Himmelfahrt mine, Freiberg, has been analyzed by H. Schulze; it has the following composition:

SiO_2	47.88
TiO_2	Trace
SnO_2	0.02
Al_2O_3	35.16
Fe_2O_3	1.92
CaO	0.48
MgO	1.11
K_2O	10.08
Na_2O	0.41
H_2O	4.02
F	?
Total	101.08

Moreover, this clayey decomposition product of the gneiss contains newly formed rutile needles and small plate-like crystals of octahedrite. The last named mineral, however, is also formed by the normal decomposition of the gneiss at the earth's surface. Finally, the rutile is accompanied by fine brown needles, determined as cassiterite, since 11.44% of SnO_2 was found in the heaviest portion of the clayey ingredients. While the material for the titaniferous minerals is found in the biotite of the gneiss, the tin must come from the vein fissure, and in fact the vein is known to contain cassiterite-bearing zinc-blende.

The crystals of arsenopyrite, so often found scattered through the decomposed gneiss of Freiberg, certainly result from the immigration of material from the vein. In the Morgenstern mine arsenopyrite is so abundant in the vein wallrock that the rock was mined for that mineral. At this same locality the decomposed country rock also contains widely distributed secondary impregnations of pyrite, galena, sphalerite and native silver[1].

A remarkable impregnation of decomposed gneiss with cuprite, braunite, blende and galena occurs in the Weisser Lowe Spat, southeast of Freiberg, the two first named minerals being entirely absent in the stringer veins themselves.[2]

[1] B. v. Cotta: 'Erzlagerstätten.' Vol. I, 1859, p. 209 *et seq.*

[2] W. Vogelgesang: 'Erzgänge südöstl. von Freiberg.' 1854. Cotta's Gangstudien, II, p. 82. Compare with F. Sandberger: 'Untersuchungen über Erzgänge,' II, p. 343.

Sericitization, as this alteration is termed, is a common feature of American mineral veins. It is a characteristic feature of the Butte, Montana, copper veins and, according to Lindgren, is typical of many gold veins in granite, especially in Idaho. It takes the place of the kaolinization typical of normal weathering. In the gold-quartz veins of California[1] sericitization is accompanied by a segregation of calcite, which, however, is a subordinate mineral in the lodes themselves. In this alteration the normal ferromagnesian silicates and feldspars of the granite are first attacked and altered to aggregates of sericite and calcite, the sericite sometimes passing through a chloritic transition stage. Next the quartz, too, is replaced. Ilmenite is changed to rutile, and a migration of new material appears in the form of sulphides, especially pyrite, as well as arsenopyrite, sometimes carrying inclusions of sericite scales.

The following analyses given by Lindgren illustrate the character of the alteration:

I is a fresh granite (by G. Steiger).

II is a sericitized granite, both from Idaho, Silver Wreath tunnel, Boise district (by G. Steiger).

III is a fresh diabase from Grass Valley, California (by H. N. Stokes).

IV is a diabase from the vein wall; North Star mine, same locality (by W. F. Hillebrand).

Analyses of Fresh and Altered Rock.	I	II	III	IV
SiO_2	65.23	66.66	51.01	45.74
TiO_2	0.66	0.49	0.98	0.36
Al_2O_3	16.94	14.26	11.89	5.29
Fe_2O_3	1.60	0.67	1.57	0.13
FeO	1.91	2.41	6.08	9.06
FeS_2	.....	.....	1.73	0.49
MnO	Trace.	Trace.	Trace.	0.26
CaO	3.85	3.37	10.36	23.85
BaO	0.19	.....	.....	.....
MgO	1.31	0.95	8.87	0.94
K_2O	3.02	4.09	0.15	1.29
Na_2O	3.57	.....	4.17	0.11
H_2O under 100° C.	0.18	0.36	0.24	0.22
H_2O over 100° C.	0.88	2.16	2.09	1.07
P_2O_5	0.19	0.17	0.17	0.07
SO_3	.....	.....	.....	.....
S	.....	0.95	.....	.....
CO_2	0.25	3.67	.....	18.91
	99.78	100.31	99.31	100.79

In the altered granite, small newly formed crystals of pyrite and arsenopyrite occur. The feldspar has disappeared, or at most only its outlines

[1] W. Lindgren: 'The Mining Districts of Idaho Basin,' etc. Extr. 18th *Ann. Rep.* U. S. Geol. Surv., 1898. Also 14th *Ann. Rep.*, part II, pp. 243–284, and 17th *Ann. Rep.*, part II, p. 144. Also *Bull.* Geol. Soc. Am., Vol. VI, p. 221. Also 'Metasomatic Processes in Fissure-Veins.' *Trans.* Am. Inst. Min. Eng., February, 1900, p. 80.

are well recognizable. The biotite has been replaced by sericite; titanite has become turbid; menaccanite has given rise to segregations of rutile; apatite has remained unchanged. This altered rock contains 1.55 grams of gold and 15.55 grams of silver per ton. In this process of sericitization even the quartz is attacked, particularly when calcite has been formed simultaneously with the sericite.

Lastly mention may be made of the replacement of the quartzite country rock of the silver-lead veins of the Coeur d'Alene Mountains in Idaho, into an aggregate of siderite with galena, pyrite and zinc-blende[1].

Kaolinization.

In certain cases the country rock is kaolinized, though it is now known that most of the cases so described are really examples of sericitization. According to J. Church[2], kaolinization occurs in the andesitic rocks of the Comstock Lode, being formerly regarded by him as the cause of the great heat of the water rising in that lode, the cause being thus confounded with the effect. Kaolinic formations also play a great part in the ore deposit of Broken Hill.

The gold veins of Nagyág are accompanied by masses of altered rocks, which have been carefully investigated. The clayey material resulting from a decomposition of the hornblendic dacites (andesite) represents an incipient kaolinization, first described by B. von Inkey[3]. A large amount of such clay was separated by F. Kolbeck[4] into its various components by means of elutriation, treatment in iodide solutions, etc. The most abundant ingredient was a mineral typical of micaceous schists. This light, greenish-gray, fibrous, scaly-textured mineral was analyzed. The composition, after F. Kolbeck, is given under A. Minute crystalline groups of arsenious, auriferous and argentiferous iron pyrite crystals, were also noted together with rounded aggregates of octahedrite, murky plates of barite, short columns of apatite and crystals of zircon of ideal sharpness. The last two minerals are primary, unaltered minerals of the dacite. The chemical composition of this rock, after Doelter[5], is given under B.

Analyses of Kaolin and Altered Rock.	A	B
SiO_2	48.67	58.01
Al_2O_3	39.30	18.19
Fe_2O_3	0.30	3.40

[1] Lindgren: Metasomatic Processes, etc., *op cit.*, p. 103.

[2] J. A. Church: 'The Comstock Lode,' *Trans.* Am. Inst. Min. Eng., 1879.

[3] B. v. Inkey: 'Nagyág und seine Erzlagerstätten.' Budapest, 1885.

[4] F. Kolbeck: 'Untersuchungen über die Zersetzung des Quarztrachytes neben den Golderzgängen von Nagyág.' *Oesterr. Z.* f. B. u. H., 1888, No. 3, p. 25.

[5] In Tschermak's 'Mitth.' 1873, part II, p. 95.

Analyses of Kaolin and Altered Rock.	A	B	
FeO	.....	2.89	
MnO	0.25	Trace.	
CaO	0.38	7.55	
MgO	1.42	3.01	
K_2O	3.73	1.39	
Na_2O	0.13	3.92	
H_2O	5.83	1.60	loss by ignition
CO_2	0.23	.....	
FeS_2	0.43	.....	
	100.67	99.96	

Propylitization[1].

Various authors[2] have shown that the propylitic alteration of andesitic and trachytic rocks is also due to hydrothermal metamorphism accompanying the formation of mineral veins. The mode of occurrence of these rocks is best exhibited in the section Fig. 173. We cannot characterize the nature of the propylites more fitly and briefly than with the words of H. Rosenbusch:

"The names quartz-propylite and propylite (F. von Richthoven) are used to designate a greenstone-like facies of dacitic and andesitic rocks found almost always at points where these rocks have acted as bringers of ore" (that is to say, are traversed by mineral veins). "The name propylite arose from the supposition that these rocks are everywhere the oldest Tertiary eruptive rocks, as is the case in some places, and after a long period of volcanic rest reinaugurated, as it were, the eruptive processes during the Mesozoic epochs" (*pro pyle*=at the gate). The name greenstone-trachyte is an older synonym. Propylitic rocks occur near large fissure veins and vein systems in Hungary and Transylvania; at the Comstock Lode, Nevada; at Pachuca and elsewhere in Mexico, and in the Andes of South America, etc. The characteristic feature of the propylitic facies consists in the loss of the glassy habit of the feldspars; in the chloritic alteration of the hornblende, biotite and pyroxenes (often with an intermediate stage of a uralite) with an accompanying development of epidote. There is a simultaneous alteration of the normal andesitic groundmass into holycrystalline granular aggregates of feldspar, quartz, chlorite, epidote and calcite, and in a considerable development of pyrite. The impregnation with pyrite points to hydrothermal processes as the common cause of both the ore content and of the alteration of the rocks, which as

[1] G. F. Becker demonstrated the secondary nature of propylite in his work on the Comstock lode. See *Monograph* No. III, U. S. Geol. Survey. (W. H. W.)

[2] M. E. Wadsworth: *Bull.* Mus. Comp. Zool., 1879, Vol. V, pp. 281-286. B. v. Inkey: 'Nagyág und seine Erzlagerstätten,' Budapest, 1885. H. Rosenbusch: 'Elemente der Gesteinslehre,' 1898, pp. 302-303. Also 'Comstock Lode,' p. 329, l. c. H. Böckh: 'Vorl. Bericht über das Altersverh. d. Eruptivg. v. Selmeczbánya,' 1901, Földtani Közlöny, Vol. XXXI.

shown by Lindgren is very different from normal weathering. Analyses 1 and 2 below give the composition of such rocks. The propylitic alteration also occurs with certain modifications in trachytes and liparites, and is indeed also found in the more basic rocks of the basalt, melaphyre and diabase families.

Analyses of Comstock Rocks.	1	2
SiO_2	66,34	64,62
Al_2O_3	14,80	11,70
Fe_2O_3	4,07	..
FeO	..	8,39
MgO	0,92	1,18
CaO	2,99	8,96
Na_2O	5,16	3,13
K_2O	3,19	1,95
H_2O	3,34	1,02
	100.81	100.95

1. Quartz propylite, Golconda, Washoe.
2. Quartz-free propylite, Sheep Corral cañon, Virginia range, Washoe.

Silicification.

A silicification of the country rock, sometimes preceded by dolomitization, is frequent both in and alongside of veins cutting limestones. As described by Lindgren[1], the limestone is in such cases usually transformed into an exceedingly fine crystalline aggregate of interlocking quartz grains (jasperoid). Sometimes, despite a complete replacement, the approximate outlines of foraminifera, shells and other fossils may be recognized in it. Similar aggregates of vein quartz are distinguished by a much coarser grain. Minute quartz dihexahedrons are also known in limestones of mining regions, for example, from Bleiberg, in Carinthia. Feldspars and even hornblende and other bisilicates may also be replaced by quartz. At Altenberg we sometimes find a silicification of the rocks near tin veins. This phenomenon is of very common occurrence in the country rock of the quicksilver veins of California. It also occurs in some lodes of Schemnitz[2]. Sometimes the dolomitization and silicification of limestones is also accompanied by an introduction of iron as siderite or as pyrite.

Alteration of Limestone into Ore-bearing Pyroxene-Epidote Rocks.

According to G. vom Rath[3] and B. Lotti[4] the Eocene clay shale and intercalated limestone beds, in which the quartzose copper veins of Caparne

[1] W. Lindgren: 'Metasomatic Processes in Fissure Veins.' *Trans.* Am. Inst. Min. Eng., Vol. XXX, p. 578.

[2] H. Böckh: l. c., p. 398.

[3] G. vom Rath: 'Aus der Umgeb. v. Massa Marittima,' *Z.* d. D. G. G., 1873.

[4] B. Lotti: 'Descr. geol.-mineraria dei Ditnorni di Massa Marittima,' Rome, 1893, pp. 73-75.

Vecchie and Serrabottini occur, near Massa Marittima, has undergone a very peculiar metamorphism. While the clay slate remains unaltered, or is slightly silicified and coated along transverse fissures with crusts of epidote and quartz, the limestone beds have either been altered into an aggregate of pyroxene and epidote, carrying pyrite, chalcopyrite, blende and galenite, or have been replaced, wholly or in part, by a mixture of silica and pyrite.

The phenomenon strongly suggests the action of contact metamorphic processes accompanying plutonic masses.

Alteration of the Country Rock into Greisen or Zwitter.

In tin veins the country rock is altered for a distance of several centimeters from the vein walls, sometimes even more, into 'tin stuff' (zwitter), or, as it is called in granitic country rock, greisen. This fact has long been known, having been described and figured by J. F. W. Charpentier, from the Erzgebirge, and subsequently has been carefully studied by the searching methods of modern petrography. Much has already been said on this point in treating of tin veins, page 202.

The alteration consists in the complete replacement of the feldspar and brown mica by quartz, together with lepidolite, topaz, tourmaline, fluorite, kaolinite, cassiterite, arsenopyrite, wolframite and other minerals characteristic of the tin deposits. When this rock contains much cassiterite and topaz, it becomes pay ore and the alteration bands are workable pay-streaks. In this way the beautiful pseudomorphs of cassiterite and quartz are formed as replacements of the large orthoclase crystals, which occur as phenocrysts in granite from St. Agnes, in Cornwall. The chemical composition of the greisen or zwitter varies with the mineralogic constitution of the original rock.

In an alteration of this nature the Altenberg granite has lost about 3% silica and 2% potash and has taken up 4% ferrous oxide and ½% oxide of tin.

The following table shows the chemical composition of the normal and the altered rock (after K. Dalmer[1]):

	1	2	3
SiO_2	74.68	70.41	79.73
TiO_2	0.71	0.49	..
SnO_2	0.09	0.49	1.43
Al_2O_3	12.73	14.86	14.31
Fe_2O_3	..	1.42	..
FeO	3.00	5.09	..
MnO	..	0.29	..

[1] K. Dalmer: 'Erläuterungen zu Section Altenberg-Zinnwald,' Leipzig, 1890, p. 56.

	1	2	3
CaO	0.09	0.21	..
MgO	0.35	0.09	..
K_2O	4.64	3.01	..
Na_2O } Li_2O }	1.54	0.98	..
Fl	Not det.	3.10	4.53
	99.50	100.44	100.00

1. A normal granite from Altenberg (analysis by Rube).

2. Greisen made from it; poor in quartz and rich in lepidolite (Dalmer).

3. Another specimen of the same kind especially rich in quartz and topaz (Dalmer).

When a porphyry or schist constitutes the country rock the 'zwitter' formed from them varies accordingly.

Further data on the cassiterite content, etc., of greisen, are found on page 215.

At Thelemarken, Norway, the granite adjacent to the copper veins and stringers is altered to greisen[1], whose mica is free from lithia.

Greisen may also occur about silver-lead veins, as shown by the description by Haworth of the silver mines east of Ironton, Missouri[2]. Veins of quartz, argentiferous galenite, iron pyrite, and chalcopyrite supposedly of pre-Cambrian age, traverse a granite which along the vein walls has been transformed into a true greisen. The simultaneous occurrence of zinnwaldite, topaz, fluorite, wolframite, muscovite and sericite, proves these lodes to closely resemble true tin veins.

Tourmalinization and Topazization.

A closely allied phenomenon to that just described is the impregnation of the country rock of veins with tourmaline.

This feature has long been known in the small vein fissures formerly worked for tin ore, which contain quartz, tourmaline and cassiterite, and lie in andalusite-mica-rock of the Auersberg region, near Eibenstock, in the Saxon Erzgebirge. The unaltered rock is itself the result of the contact metamorphism of a phyllite by a tourmaline granite. The impregnation of the vein wallrock with tourmaline, together with quartz, cassiterite, chalcopyrite, and in rarer cases with traces of gold, extends for a distance of about 0.5 meters from the vein (Schröder[3]). Fig. 189 gives a section of such a zone of impregnation.

[1] Lindgren objects to this use of the term greisen. 'Metasomatic Processes in Fissure Veins,' 'Genesis of Ore Deposits,' Am. Inst. Min. Eng., p. 563.

[2] Missouri Geol. Survey, 1895, Vol. VIII, p. 83.

[3] M. Schröder: 'Erläuterungen zu Section Eibenstock,' Leipzig, 1884, p. 38.

On a large scale tourmalinization and topazization of the country rock of tin veins has taken place on Mount Bischoff, in Tasmania, as will be related in detail under the heading of 'Tin Placers.' The quartz crystals of the slate of that locality show various gradations to a complete replacement and the formation of tourmaline-fels. The alteration is especially marked in the case of quartz porphyries whose orthoclase phenocrysts are replaced by cassiterite, pyrite, magnetite, arsenopyrite and fluorite.

This is the most appropriate class in which to place the topaz rocks (Topasbrockenfelse) from the old tin deposits of Schneckenstein, on the western border of the same Eibenstock granite mass studied by Schröder[1]. The deposits hold fragments of tourmalinized schist cemented by topaz, while near by the quartz porphyry dikes of the Saubach Valley show intense topazization.

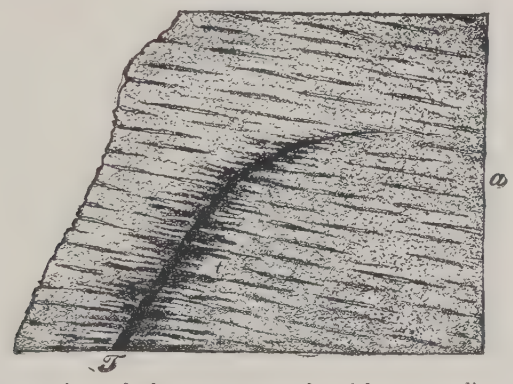


Fig. 189.—Impregnation of the country rock with tourmaline. (M. Schröder.) a, andalusite mica rock; T, tourmaline-quartz vein; t, tourmaline schist.

A tourmalinization of the country rock has also been observed in the gold-bearing copper veins of Chile (see p. 220).

As an appendix mention may also be made of the fluoritization of the crystalline limestone of Berggiesshübel in the vicinity of stringers of the tin veins. The quartz-fluorite mixture of Cripple Creek, too, is regarded by W. Lindgren as formed by metasomatic replacement of feldspar and other minerals.

Metasomatic Replacement of Country Rock by Ore.

This process, which has been repeatedly referred to already, is of widespread occurrence. It has been very carefully studied by W. Lindgren. This author has described replacements of country rock by pyrite, mar-

[1] M. Schröder: 'Erläuterungen zu Section Falkenstein,' Leipzig, 1885 p. 40.

casite, chalcopyrite, arsenopyrite, magnetite, kaolinite, zinc-blende, native gold, silver and copper. The occurrence of disseminated crystals and grains of these sulphides in country rock has been known for a long time, as already mentioned.

The proof that these scattered sulphide minerals are due to replacement has been demonstrated by Lindgren by the study of thin sections under the microscope. As an example we may mention the micro-structure of galena ores of Elkhorn, Mont. Fig. 190 shows in thin section the replacement of a crystalline dolomitic limestone by this ore. This mineral is apt to replace calcite and dolomite, also quartz and silicates, as will be shown in the de-

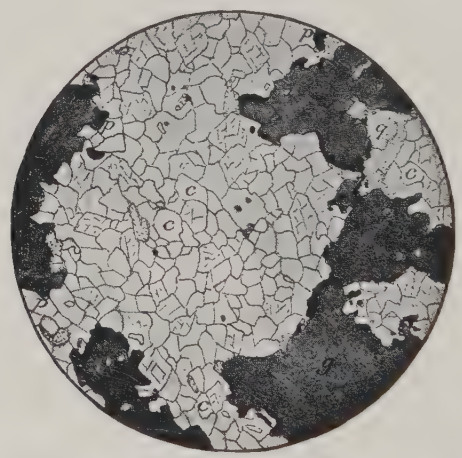


Fig. 190.—Limestone (c) replaced by galena (g), prite (p) and secondary quartz (q). Elkhorn Mine, Montana. (Enlarged 12 times.)

scription of epigenetic ore stocks. The long known alteration of the Zechstein limestone close to the mineral veins of Kamsdorf belong to this category.

Alteration of the Hanging-Wall Rock.

T. A. Rickard[1] was the first, so far as we know, to point out that the two walls of a lode often show a great difference in the degree of decomposition. In the hanging-wall the country rock is usually changed into sericite or other alteration products, to a much greater distance than in the foot-wall. The explanation of this observation, which needs confirmation by extended observations in other districts, may be the following: in the masses of gravel

[1] T. A. Rickard: 'Vein-Walls,' *Trans.* Amer. Inst. Min. Eng., Vol. XXVI, 1897, p. 193.

and gouge produced by friction of the vein walls, the clay settles out through gravity on the foot-wall, even when the fissures were entirely filled with ore. This foot-wall gouge forms an impervious or nearly impervious lining, preventing the thermal waters from penetrating further into the foot-wall country rock and there causing rock decomposition.

This theory agrees well with what F. A. Moesta[1] says of the so-called *mantos,* that is to say, zones of impregnation and alteration in the Jurassic limestone or country rock of the famous silver veins of Chañarcillo (see p. 279): "It is a remarkable fact that the *mantos* are developed by preference in the hanging-wall, while the continuous and perfect foot-wall is formed of unaltered rock. On the hanging-wall side of the vein the country rock is netted with numerous ore-bearing fissures and lode stringers, and is so richly impregnated with ore that its silver content rises to 1% and above, so that it is often profitably worked for a distance of 12 meters from the lode." At greater depths, indeed, the *mantos* are mostly developed on both sides of the lode, but grow generally rarer and poorer. Within this impregnated country rock (*mantos*) the lodes of Chañarcillo contain the richest orebodies. Hence Moesta believes that the original character of the country rock has had an influence in their development and that they represent zones of enrichment whose origin he associates with the intrusion of the greenstones. The rock alteration in these *mantos* consists, among other things, in a strong silicification. The following analyses made by Moesta show the chemical difference between such a *manto* and the undecomposed rock belonging to the same stratum in the foot-wall of the lode:

	Manto.	Unaltered Rock.
SiO_2	47.97	22.82
Al_2O_3	6.22	
Fe_2O_3	3.90	3.53
MgO	16.71	11.46
CaO	9.65	29.73
CO_2	11.64	31.09
K_2O+Na_2O	1.27	1.69
AgCl	1.55	..
C	..	0.93
	98.91	101.25

Geologic Age of Mineral Veins.

The origin of a vein is generally supposed to be the result of two acts which follow each other very closely: 1, the opening of the fissure; 2, the filling thereof.

[1] F. A. Moesta: 'Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen des Silbers in der Natur.,' Marburg, 1870, p. 26.

From examples already given it is inferred that fissures have been formed in all periods of the earth's history and are still forming, and hence vein fillings exhibit great variety in age. Another feature of great importance is the repeated opening of many vein fissures and the resulting formation of vein fillings of successive ages in the same vein. Such action continued for a long period may result in changes in the nature of the solutions introduced, and thus the character of the successive fillings may differ. A vein may even contain two or three bands which cannot be classified in the same group or character of vein formation. For example, some lodes of the Himmelsfürst mine near Brand consist of a band of the carbonspathic, and another of the pyritous-galena-blende veins (formation).

The age of a vein[1] can be determined within certain limits when we know the age of the rock cut out by it, and the vein is in turn cut by another rock whose age is known. Of course, this differs from a cutting off or termination of the vein as a result of a different texture or condition of coherence of the other rock (see p. 123). On the contrary, it must be known from observation that the vein had been formed before the deposition of the second rock; a fact known, for example, if fragments of the vein are found in the rock. Other criteria for the determination of age consist in the presence of other fissures of known age; fault fissures; eruptive dikes and mineral veins in which natural or artificial exposures show whether they cut off the vein in question or not. In any case one can only determine the relative age. All we can find out is whether a vein is actually younger or older than another geologic formation. The country rock cut by the vein only gives the older age limit. The vein may be very much younger than the country rock. This is especially striking in the lead or zinc deposits found (not in genuine veins) in the Silurian limestones of Missouri. In these deposits a part of the galenite and zinc-blende is of Pleistocene age, for it contains bones of *elephas* coated with galenite. The same is true of the Tertiary and Pleistocene limonites found in cavities in Jurassic limestones.

The determination of the relative age of veins may be illustrated by a few examples:

At Freiberg the ores of the silver quartz veins are traversed by quartz-porphyry dikes, whose Permian age has been demonstrated; hence they are older than the Permian. Conversely, the pyritous-blendic lead veins traverse the Permian quartz-porphyries, and hence are younger than these.

The ore lodes of Joachimsthal traverse the Permian quartz-porphyry

[1] H. Höfer: 'Zur Bestimmung des Alters der Gänge,' *Oesterr. Z. f. B. u. H.*, Vol. XLVII, 1899.

dikes, but are in the main cut by the Upper Oligocene basalts, only a few insignificant younger ore stringers being found in the basalt. Moreover, as the fissure formation of that locality very probably coincides with the main uplift of the Erzgebirge, which took place in Oligocene time, the origin of the mineral veins may be very properly referred to the Oligocene period. The same relation exists between the cobalt-silver veins of Annaberg and the basalts of the Erzgebirge. Some gold quartz veins of Australia traverse sedimentary and eruptive rocks of Silurian and Devonian age, but are themselves covered by Carboniferous rocks. The pre-Carboniferous age of those veins is also indicated by the occurrence of gold in the lowest Carboniferous conglomerates.

Sometimes it even seems possible to determine the relative age of the various divisions of the lode filling. Thus, according to F. Klockmann[1], the quartz and calcite in the mineral veins of the Upper Harz are probably of Permian age. On the contrary, the barite was probably introduced much later, during or after the Zechstein period, for at Rösteberg near Grund, barite occurs in the Zechstein dolomite. The siderite stringers and the strontianite are probably still more recent. On the other hand, the ore minerals do not seem to have been restricted to the oldest period of mineralization, for galenite also occurs in fissures and cavities in the Zechstein beds of Grund and Lauterberg. Moreover, in the upper Harz, certain veins have been clearly shown by von Koenen[2] to be of Miocene to Pliocene age.

It was formerly believed that certain types of veins were associated with definite geologic periods. Recent observations, however, show the danger of such a generalization. What is true of a limited area may not prevail over the entire surface of the globe. While, for example, at Freiberg, the rich (*edle*) quartz veins were found to be older than the Permian, in the closely similar occurrences in Mexico the post-Jurassic age has been proved beyond doubt (p. 266). Thus, in former times, when all granites were regarded as Paleozoic or older, that age was also assigned to the tin lodes associated with the granites. At present, however, occurrences of both are known which are much younger. The lodes of Altenberg and Zinnwald, for example, are, according to K. Dalmer[3], of post-Carboniferous age, and in the province of Pisa, in upper Italy, tin veins cut Liassic strata.

Gold vein deposition is, according to Lindgren, associated with certain

[1] F. Klockmann: 'Berg- und Hüttenwesen des Oberharzes,' Stuttgart, 1895, p. 49.

[2] A. v. Koenen: 'Ueber die Dislocationen westlich und südwestlich vom Harz,' *Jahrb.* d. k. preuss. geol. Landesanst., 1893, pp. 68-82.

[3] K. Dalmer: 'Altenberg-Graupener Zinnerzlagerstätten,' *Zeit. f. Prak. Geol.*, 1894, p. 314.

periods of igneous activity of definite geologic age[1]. Thus in North America certain periods of deposition stand out prominently. His investigations show primary gold veins of (1) pre-Cambrian, (2) Mesozoic, (3) Tertiary ages[2].

Association of Certain Types of Veins with Particular Eruptive Rocks.

Since the oldest period of mining the miner has recognized certain eruptive rocks as carriers of ore. This is especially well known in the case of tin veins, associated with granite, as shown by the examples mentioned in an earlier part of this work, from the Erzgebirge, Cornwall, Malacca, Tasmania, etc.

Many other illustrations of such dependence have been furnished, especially by W. Möricke[3].

In Chile the gold-bearing copper veins are associated with moderately or highly siliceous eruptive rocks, such as quartz-gabbros, quartz-diorites, syenites, amphibole granitites, quartz-porphyries and rhyolites. Similarly in Hungary gold veins of diverse character are associated with Tertiary quartz-andesites (Verespatak, Nagyág, Boicza) or rhyolites (Königsberg near Schemnitz, Telkibanya). In California the gold quartz veins are in intimate relation to granitic rocks, as is also the case in the Ural region (Kotschkar, Berezovsk, etc.). They are also often found in connection with amphibolitized diabases (Australia, Mashonaland and Guiana).

Similarly in Chile the rich silver-copper veins are most commonly found associated with basic plagioclase-augite rocks, such as diabases, augite-porphyries, augite-andesites. Mention may be again made of the association of the Pribram lead veins with the diabases and diorites of that locality, as well as of the preference shown by the copper ores for melaphyres or diabase porphyries, as on Lake Superior. This subject has recently received much attention from Spurr and his critics[4]. Spurr has suggested that there are 'Metalliferous Provinces' as distinct and well defined as Petrographic Provinces, but not necessarily coincident with the latter.

[1] 'The Geological Features of the Gold Production of North America,' *Trans.* Am. Inst. Min. Eng., Vol. XXXIII, p. 790.

[2] Paragraph revised by translator.

[3] W. Möricke: 'Die Gold-, Silber- und Kupfer-Erzlagerstätten in Chile und ihre Abhängigkeit von Eruptivgesteinen,' Freiberg, 1897.

[4] 'A Consideration of the Igneous Rocks and their Segregation or Differentiation as related to the Occurrence of Ores,' *Trans.* Am. Inst. Min. Eng., Vol. XXXIII, p. 288. *Vide* Purington, 'Ore Deposits, a Discussion,' p. 68.

A REVIEW OF THE VARIOUS THEORIES OF THE ORIGIN OF MINERAL VEINS.

No other branch of geology has in former times yielded so great a number of theories and speculations as those upon the origin of mineral veins. These curious earlier hypotheses have been summarized by A. G. Werner[1] and later with greater detail by K. A. Kühn[2] and B. von Cotta[3]. They will not be discussed in detail, but brief mention will be given of Werner's views. According to him, mineral veins are formed by the filling of open fissures with chemical or mechanical precipitates from waters from above, or, as he expressed it, "from a wet solution mostly chemical, covering the region where the lode spaces existed, and at the same time filling the empty open lode spaces."

The various theories that sprung up during the time after Werner may be divided, as was done by Freiherr von Herder[4], into various groups, which we will now proceed to discuss.

It should be thoroughly understood, however, that all mineral deposits are not formed in the same way and are not explainable by a single theory. We will in each case enumerate the various groups of veins for which one or the other theory seems to us applicable.

(A) Congeneration Theory.

The old congeneration theory, according to which veins are not fissure fillings at all, but were produced simultaneously with the country rock, is now merely of historical interest. It becomes, however, debatable when modified by the clause "or the veins are parts of the rock masses subsequently changed by alteration," which corresponds to the views of J. F. W. Charpentier. In this sense many tin veins might perhaps be ranked under this head. Likewise the ore-segregations in eruptive rocks, which sometimes assume the form of lodes, as in the case of the bands (schlieren) of chromite ore, shown in Fig. 5, might be described as formed by congeneration.

(B) Descension Theory.

According to the descension theory veins are fillings of fissures which wedge out below. The vein filling came in from above and is quite independent of the nature of the country rock. This origin, as just noted, was applied by A. G. Werner to all mineral veins, and naturally greatly in-

[1] A. G. Werner: 'Neue Theorie von der Entstehung der Gänge,' Freiberg, 1791.
[2] K. A. Kühn: 'Handbuch der Geognosie,' Vol. II, p. 666, Freiberg, 1834-36.
[3] B. v. Cotta: 'Erzlagerstätten,' 1859, Vol. I, part 2, p. 175.
[4] Freiherr von Herder: 'Der Tiefe Meissner Erbstolln,' Leipzig, 1838.

fluenced the views regarding the future of mining enterprises in mineral districts, for example, at Freiberg, since according to this theory the ore deposits would be confined to the uppermost part of the earth's crust. This theory, originating with so noted a man, was not vigorously opposed until, in 1840, Fr. von Beust[1] brought the opposition to a focus and upset the theory. The last adherent of the Werner theory in its general sense was Ch. Moore[2], who as late as 1869 applied this explanation to the veins of lead ore in the Carboniferous limestone of the Mendip and Alston districts in England, in which he affirmed that he had found Jurassic fossils.

True mineral veins really formed by solutions bringing material from above are probably very rare. The small stringers of rich copper ore found beneath the gossan in the Huelva pyrite deposits are of this class (see under Huelva). Their filling is derived from the pyrite decomposing to form the gossan, the rich copper ore being deposited from the solutions which seeped downward. In fact, the part of ore deposits near the outcrop often shows ore masses formed by descension, but these ores are purely of secondary origin, though sometimes of great economic importance. They have already been noted in describing the gossan of veins. Certain deposits of stalactic limonite found in veins may also be regarded as descension deposits. On the other hand, many barren veins actually exist which might justly be called descension veins.

C. G. A. v. Weissenbach[3] long ago mentioned sandstone and limestone veins formed in this way. All visitors to the Plauensche Grunde near Dresden are familiar with the narrow fissures seen in the syenite, which are filled with a breccia of shells determinable as Cenomanian. These crevices extend downward for about two meters below the surface of the syenite which forms the contact plane of the Upper Cretaceous. This class also includes the sandstone veins of California described by Diller[4] and those noted by Cross in the granite of the Pike's Peak region in Colorado; at both localities they represent earthquake fissures, probably filled by windblown sand. Oligocene sandstone veins have also been described by Pavlov[5] in the Neocomian clay of Alatyr in Russia, and Kalkowsky[6] in the

[1] F. C. v. Beust: 'Kritische Beluechtung der Werner'schen Gangtheorie,' Freiberg, 1840.

[2] Ch. Moore: '*Rep.* on Mineral Veins in Carboniferous Limestone and their organic contents.' *Rep.* of Brit. Assn. Adv. of Sc., 1869, p. 360 *et seq.*

[3] C. G. A. v. Weissenbach: 'Ueber Gangformationen, vorzugsweise Sachsens,' B. Cotta's 'Gangstudien', Vol. I, Freiberg, 1847, p. 17.

[4] J. S. Diller: 'Sandstone dikes,' *Bull.* of the Geol. Soc. of America, 1890, Vol. I, p. 411. Whitman Cross: 'Intrusive sandstone dikes in granite,' *Idem*, 1894, Vol. V, p. 225.

[5] A. P. Pavlov: 'Dikes of Oligocene Sandstone in the Neocomian Clays of the District of Alatyr,' *Geol. Mag.*, 1896, Vol. III, p. 49.

[6] E. Kalkowsky: 'Ueber einen Oligoc. Sandsteingang an der Lausitzer Ueberschiebung bei Weinböhla.' Abh. d. Isis, Dresden, 1897, 11, p. 80.

Turonian Pläner of Weinböhla in Saxony. In the last named case a little iron pyrite has been deposited in the center of the vein.

Similar veins due to the forcing in of soft rock material from above (gouge, clay, sandstone, particularly that carrying pebbles) occur in the main coal measure of the Plauensche Grunde near Dresden, as was known to von Weissenbach, and accurately described later by R. Hausse[1]. On account of their rough walls, whose tooth-like projections extend into the coal measures, the veins are called 'combs.'

Lastly true mineral veins sometimes show certain phenomena, which can only be explained by assuming a subsequent mechanical introduction of material from above.

In the Segen Gottes mine at Zwittermühl, in the upper Schwarzwasser Valley, in the Bohemian Erzgebirge, a cobalt vein was mined. Fifty meters east of the shaft, and 140 meters below the surface, the true filling between firm walls, at this point 0.6 meter apart, was washed out and replaced for a distance of 6 meters by coarse river drift passing upward into sandy material[2]. The river pebbles consisted of vein quartz, phyllite, quartzite and quartz-phyllite, such as occur in the normal drift of the Schwarzwasser, so that there can be no doubt of their having been introduced from above after the washing out of the soft gossan ores.

In the Diepenbrok mine near Muhlheim on the Ruhr (Selbeck mines) the vein is 0.5 to 8 meters thick, and consists mainly of zinc-blende, with some galenite and quartz, occurring in continuous pay streaks up to 600 meters long. Toward the beginning[3] of the 80's, on the 30-meter level at Dahm, a mass of pebbles and sand was encountered containing river boulders up to 10 quintals in weight, together with fragments of pine wood, and also, it is stated, the tooth of a mammoth. The drift consisted of clay slate and graywacke, in part also of fragments of vein matter rich in blende. This deposit of pebbles and sand form the filling of a gorge 262 ft. (80 m.) wide that was unknown until revealed by mining operations. The deposit ran at right angles to the strike of the lode, which there is about 1 meter thick. By excavation the débris was proved to extend 5 meters below the 30-meter level (that is to say, 5 meters below the bed of the Ruhr) without reaching its lower limit.

(c) Lateral Secretion Theory.

According to the lateral secretion theory the metallic and earthy contents

[1] R. Hausse: 'Profile durch das Steinkohlenbecken des Plauenschen Grundes,' Leipzig, 1892, p. 97.

[2] Note by A. W. Stelzner from letter of E. Treptow.

[3] Short communication of Dir. Rötzel to A. W. Stelzner.

of mineral veins are derived from the country rock, the material being chemically extracted from it by invading ground-water and redeposited in the vein fissure. This idea was expressed in the early works of Ch. T. Delius[1], C. A. Gerhard[2], and Lasius[3]. It was subsequently advocated by Bischof[4], and particularly by Forchhammer[5]. Bischof proved that the chemical compounds constituting the most common gangue are present in the country rock of the veins, and expressed the conjecture that even iron, manganese, and the other metals in our ores might be derived from the silicates of the country rock (*l. c.*, p. 720), and that probably the feldspar was in most cases the real carrier of the ore. Besides iron and manganese, Forchhammer also found in many rocks some zinc, nickel, cobalt, bismuth, lead, copper, silver and gold, and he referred especially to sodium chloride as the solvent of these metals. The theory was also supported by L. Dieulafait, who demonstrated the wide distribution of barium and strontium in all crystalline rocks[6], and ascertained also the presence of analyses[7].

Wallace[8], too, explained the origin of the ore lodes of Alston Moor by the decomposition and leaching out of the lead-bearing Carboniferous limestone by atmospheric water.

Finally Sandberger[9] adopted this theory and applied it to all possible ore deposits, basing his conclusions on numerous rock analyses made or collected by himself. Thus he referred the barite content of many lode fissures to the barium present in the orthoclase of granite and other rocks as previously ascertained by A. Breithaupt. The nickel ores of veins in the serpentinized paleopicrite of Nanzenbach he ascribed to the nickel content of the olivene in the fresh rock. According to him the heavy metals of the mineral veins in the gneissoid rocks of the Spessart and the Black

[1] Ch. T. Delius: 'Von dem Ursprung der Gebirge u. d. darinnen befind. Erzadern,' Leipzig, 1770.

[2] C. A. Gerhard: 'Beitrage z. Chem. u. Geschichte des Mineralreiches,' Berlin 1773-76.

[3] G. S. O. Lasius: 'Beobachtungen über die Harzgebirge,' Hanover, 1789-90.

[4] G. Bischof: 'Lehrbuch der chemischen und phys. Geologie,' 2d ed., 1863-71, Vol. III, p. 665 *et seq.*

[5] J. G. Forchhammer: 'Ueber den Einfluss des Kochsalzes auf die Bildung der Mineralien,' Poggendorf's *Ann.*, 1855, No. 5, p. 60.

[6] L. Dieulafait: 'Existence de baryte et de la strontiane dans toutes les roches primordiaires,' etc. 'Filons métallifères à gangue de baryte.' *Comptes Rendus*, Paris, Vol. LXXXVII, p. 934.

[7] L. Dieulafait: *Compt. R.*, Vol. LXXXVIX, p. 453. Vol. XCVI, p. 70. Vol. XCVIII, pp. 568, 634.

[8] W. Wallace: 'The Laws which regulate the disposition of Lead Ore in Veins illustrated by the mining districts of Alston Moor,' London, 1861.

[9] F. v. Sandberger: 'Zur Theorie der Bildung der Erzgänge,' *Berg u. Hutten Zeit.*, 1877, No. 44 *et seq.* *Idem.* 'Ueber die Bildung von Erzgängen mittelst Auslaugung des Nebengesteines,' *Z.* d. D. G. G., 1880, p. 350 *et seq.*

Forest are derived from the dark mica of that country rock, and the difference in the metallic content of that mica is reflected in the character of the ores of these two lode areas.

In point of fact, the lateral secretion theory seems applicable to many deposits, though it is not of the general application given it by F. von Sandberger.

The following examples of mineral veins are, in our opinion, really formed by lateral secretion:

The fissures in the Quader sandstone of Saxon-Switzerland are found very frequently lined with thin plates of manganiferous limonite, this same limonite also forming a cement in the adjoining quartz sandstone. Sometimes these plates form genuine stringer veins slightly worked in former times. As magnetite and other iron ores exist in small particles in this sandstone, as in most sands, a lateral secretion and subsequent segregation in the open fissure readily suggests itself. For that matter, the iron in various rocks is often concentrated in nodular concretions within the rock itself. Iron ore deposits originating in this way are also very common in ferruginous diabase tuffs, as, for example, those in the Lahn Valley. The manganese veins in hornblende porphyry at Ilfeld, in the Harz, also seem to have been formed in this manner. The fact that they usually become impoverished at so shallow a depth as 12 meters is itself evidence of their dependence on atmospheric seepage water.

The lateral secretion theory will also account for the veins and bunches of garnierite and other nickel hydrosilicate ores in serpentine. The olivene in the peridotite of Riddles in Oregon, for example, as mentioned on page 348, contains 0.26% of NiO, and the bronzite of the same rock 0.5% NiO. In the serpentinization of the olivene rocks of the Numea region of New Caledonia cobaltiferous manganese compounds, asbolite, etc., are apt to segregate together with the nickel hydrosilicates, though not in contact with them.

This theory is also applicable to other forms of epigenetic deposits. We have already referred to it in discussing the iron ores of the Marquette district on Lake Superior.

The iron, manganese and nickel ores of the deposits just mentioned are correctly ascribed to the decomposition and leaching of the country rock. The same is true, according to F. Sandberger[1], of a great number of other metals, the mica of the crystalline country rock being regarded as the original source of the heavy metals in the fissures.

[1] Summary by Carthaus: Sandberger's 'Erzgangtheorie,' *Zeit. f. Prak. Geol.*, 1896, p. 108 *et seq.*

According to Rammelsberg's terminology the mica formula is as follows:

$$m\,R_4^{I}\,Si\,O_4,\quad n\,R_2^{II}\,Si\,O_4,\quad v.(R_2)_2^{VI}\,Si_3\,O_{12},\text{ in which:}$$

I
R = K, Na, according to F. Sandberger, also
Li, Ag, H and Fl;

II
R = Mg, Fe, according to F. Sandberger, there is also
Ca, Ba, Mn, Ni, Co, Cu, Pb, Zn;

VI
R = (Al_2), in some cases also (Cr_2).
$Si\,O_2$, sometimes partly replaced by $Ti\,O_2$ and $Sn\,O_2$.

The minute quantities of As and Sb found by F. Sandberger in many micas seem, according to him, to be combined as an acid. An entirely similar process will account, according to the same author, for the metals abundant in augite and hornblende.

The solution and leaching out of these metallic compounds was conceived by Sandberger to have been effected from above by seepage water containing acid alkalies and hydrogen sulphide. H_2S is taken up by many atmospheric waters through contact with decaying organic substances. The first results are soluble alkaline sulphides. These in turn are able to dissolve compounds of Sn, As and Sb, and to precipitate Fe, Pb, Zn, Cu and Ag as sulphides. The reactions produced by CO_2 and H_2S often take place in the presence of NH_4, formed by the decomposition of organic substances, of H_2SO_4, derived from the weathering of pyrite inclusions in country rock, and finally in the presence of organic acids, bases and salts.

The gangue minerals are supposed to originate in the same manner. Thus quartz results from the SiO_2 liberated by the decomposition of the silicates, barite from the barium in the feldspars, calcite from the lime of the feldspars, augites, hornblendes, etc., dolomite from the magnesia in micas, hornblendes and augites, fluorite from the F of the micas and hornblendes, the H_2SO_4 acting on potassium fluoride and the resulting solution, coming in contact with $CaCO_3$ producing CaF_2.

There is no doubt that the mineral contents of the seepage water (vadose) derived from the weathered materials above ground-water level by lateral secretion[1] does exert a great influence on the formation of secondary concentration of ore in the gossan zone (see p. 367), a general conclusion reached by Weed[2] and shown independently by Emmons[3] and Van Hise[4].

[1] This paragraph revised by translator.

[2] 'Enrichment of Ore Deposits by later metallic sulphides,' *Bull.* Geol. Soc. Am., 1900. 'Secondary Enrichment of Gold and Silver Ores,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXX, p. 424.

[3] 'Secondary enrichment of Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXX, p. 177.

[4] 'Principles Controlling Dep. of Ores,' *Trans.* Am. Inst. Min. Eng.,1900, Vol. XXX, p. 73.

It is also possible that these ideas are applicable to certain primary orebodies of veins, but for the great majority of mineral veins they are untrue, as has been convincingly demonstrated by A. W. Stelzner. The fundamental error of this theory originated in the faulty analytical methods of F. Sandberger in tests made to determine the primary content of heavy metals in the country rock, and through his disregard of the secondary impregnation phenomena universally prevailing along vein fissures, whereby the metals characteristic of the lodes were enabled to penetrate far into the country rock. Stelzner's[1] investigations were carried on at two universally known mining districts, viz.: Pribram and that of Freiberg.

In the case of Pribram, F. Sandberger supposed the metallic contents of the mineral veins to come from the diabases accompanying them. Now, although his analyses actually show a lead and silver content in the diabase, yet this is only due to metallic material carried from the mineral veins into the country rock. F. Sandberger thought that if he decomposed the rock with hydrofluoric acid he would decompose all the silicates, but none of the particles of secondary ore, and if, therefore, he was able to demonstrate lead and silver in the solutions thus obtained, the metals thus found must have been chemically combined with the silicates that were dissolved by the hydrofluoric acid. F. Kolbeck and A. Schertel in Freiberg pointed out the flaw in this reasoning, and showed that hydrofluoric acid will also decompose galenite and other sulphidic ores. This demolished Sandberger's alleged proof of an original metal content in the diabase.

For Freiberg Stelzner[2] chose another method of investigation. With exceeding labor and care he crushed samples of the typical biotite-gneiss which forms the country rock of the veins, and, with the aid of the Thoulet and Klein solutions, separated out the various mineral constituents, collecting enough perfectly pure material of each mineral for analyses by competent chemists. As the rock samples consisted of perfectly fresh material, far from the zones of decomposition accompanying the veins, these analyses must show conclusively whether or not the metals characteristic of the Freiberg lodes were present in the silicates of the gneisses. It is not probable that such exceedingly accurate separations of the mineral constituents of rocks of complicated composition were ever made before. When it was found that despite this extraordinary care the mica thus obtained still enclosed particles of metallic sulphides, the problem was presented to the analyst by Stelzner in this form: "Show by test whether mica possibly containing inclusions of small quantities of metallic sulphides also contains

[1] A. W. Stelzner: 'Die Lateralsecretionstheorie und ihre Bedeutung für das Pribramer Ganggebiet,' B. u. H. *Jahrb.* der k. k. Bergak, Vol. XXXVII, 1889.

[2] A. W. Stelzner: 'Beiträge zur Entstehung der Freiberger Bleierz- und der erzgebirgischen Zinnerzgänge,' *Zeit. f. Prak. Geol.*, 1896, pp. 377-412.

metals in its own mass, that is to say, as original chemical constituents of silicates." The mica was, therefore, triturated with bromine and the pyrite particles leached out before the material was submitted to analysis.

Among the results thus obtained we give the following by H. Schulze:

	Ludwigschachter Gneiss.	Brown Mica from Himmelsfürster Gneiss.	Wegefahrter Gneiss.
SiO^2	33.09%	34.28%	34.38%
TiO_2	3.05 "	4.04 "	1.88 "
Al_2O_3	20.03 "	15.58 "	22.41 "
Fe_2O_3	2.85 "	15.67 "	12.66 "
FeO	17.94 "	10.01 "	8.10 "
MnO	0.26 "	0.42 "	Trace.
MgO	8.70 "	9.52 "	9.48 "
CaO	0.94 "	0.88 "	0.72 "
K_2O	8.88 "	5.58 "	7.13 "
Na_2O	0.48 "	0.42 "	1.56 "
Li_2O	Trace.	.....	.....
H_2O	3.75 "	2.75 "	2.02 "
F	.....	.....	.....
SnO_2	.....	.....	.....
Insoluble residue	.....	0.26 "	.....
Heavy metals, according to Schulze	99.97% Ni, Co, Cu, Zn	99.41% Ni, Co, Cu	100.34% Ni, Co
Heavy metals, according to Sandberger	Ag, As, Pb, Zn, Co, Ni, Cu	Ag, As, Pb, Zn, Co, Ni, Cu, Sn	Ag, As, Pb, Zn, Co, Ni, Cu, Sb

The analyses of the feldspars of the Freiberg gneisses show a small amount of BaO and SnO_2, which can be used as an argument for a lateral secretion theory.

For example, according to H. Schulze, the orthoclase from the Ludwigschachter gneiss contained:

SiO_2	65.18%
Al_2O_3	18.44 "
Fe_2O_3	0.15 "
BaO	0.08 "
CaO	1.05 "
MgO	0.08 "
K_2O	13.33 "
Na_2O	1.64 "
SnO_2	0.03 "

While the oligoclase of the same rock held:

BaO	0.03%
SnO_2	0.08 "

Finally, the heavy metals were also found in the pyrrhotite, present in small amounts disseminated through the gneiss; 715 grams of Wegefahrter gneiss contained, according to A. W. Stelzner, 4.65 grams pyrrhotite, and this according to an analysis by H. Schulze gave:

Ni	0.61 per cent.
Co	0.12 "

From these and many other similar results of his careful investigations, A. W. Stelzner was able to show that the lateral secretion theory does not apply to the Freiberg ore lodes in any manner whatever, at least as regards the ores. In fact, the metals most characteristic for Freiberg, lead and silver, were not found at all in the silicates of the country rock, not even in traces, hence the relation of the nickel and cobalt content found in the pyrrhotite in the presence of this absolute lack of lead and silver is totally different from that which exists between these two ores in the Freiberg lodes. In the case of the latter, the proportions of the various metals, calculated from the actual metallic product of the mines is, according to Stelzner, as follows:

1 nickel, 731 silver, 85,679 lead, 2,198 copper, 3,259 zinc, 43,605 sulphur, 5,839 arsenic.

Hence, if the Sandberger theory were correct, these other metals ought to be present in the constituents of the gneiss in correspondingly greater amounts compared to the nickel. In view of these facts it must also appear very improbable that the BaO content of the feldspars of the gneisses furnished the material for the barite in the veins, and that the carbonates occurring in the Freiberg lodes are derived from the country rock.

In recent time the gold veins of Australia and New Zealand have also been studied and their ores tested with a view to ascertaining whether their origin might be explained by means of the lateral secretion theory. There, too, the result was negative. This important and thorough investigation was carried out by Don[1]. He tested over 400 samples of country rock from different depths, and at different distances from the lodes, for gold, silver and sulphides, using the surest and most refined methods. The gold was determined by the dry way, with specially purified lead, using in most cases more than two kilograms of rock material.

In no case did he succeed in demonstrating the presence of gold in rock that was free from pyrite and other sulphides, and in deeper zones, where both the lodes and the country rock were as yet undecomposed, the sulphides contained in the rocks did not, by any means, always contain gold. On the contrary, the gold content usually appears only in close proximity to the lodes, so that an immigration of the gold-bearing sulphides from the fissures can not *a priori* be denied. The conditions were somewhat different in the 'vadose' region in Posepny's sense, that is to say, *above* the groundwater level. There the gold content of the country rocks is not merely confined to the proximity of the lode, but extends much farther laterally and is at the same time much greater. Don explains this by the fact that the

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes,' *Trans.* Am. Inst. Min. Eng., 1898, Vol. XXVII, p. 564.

gossan is in constant formation and migrates downward during progressive denudation, causing a good deal of gold to pass into solution and to be redeposited in the decomposed country rock of these upper regions.

The principal solvent, according to Don, is chlorine. This, according to him, is formed as follows: The H_2SO_4 set free by the oxidation of sulphides combine with chlorides, forming HCl, and from this and the higher manganese oxides so common in the gossan the chlorine is developed. Free HCl was shown to exist in most fresh mine waters. The redeposition of gold is also proven by its occurrence inside of old mine timbers.

A weighty argument against the general application of the lateral secretion theory is the occurrence of veins of entirely different mineralogic and chemical character in the same rock; for example, in the homogeneous gneiss of the Freiberg district, lodes of highly varying type are found side by side; at Butte, Montana, the strongly contrasted types of copper and of silver veins occur in a mass of homogeneous basic granite. Conversely, one lode, or a number of similar lodes, traverse masses of very different rocks without showing any material change in the chemical nature of their filling, and frequently the same vein types recur in entirely different rocks. Thus at Freiberg the country rock of the pyrite-blende lead ores is gneiss; at Svenningdal, in Norway[1], it is limestone, with micaceous hornblende schist and granite.

The lateral secretion theory, as A. W. Stelzner has very fitly remarked, is not reconcilable with the presence of mineral crusts showing a successive deposition at a different time of the ore and gangue minerals filling the fissures. A progressive lateral leaching out of the country rock should result in a constant composition, or, at any rate, of a uniform character of the solutions passing into the vein fissures. Any general application of this theory is therefore decidedly impracticable.

(D) The Ascension Theories.

The various ascension theories assume that the material filling the vein fissures and impregnating the wall rocks rose from an unknown depth in three ways:

1. In a molten condition—the injection theory.
2. In the form of gases and vapors—the sublimation theory.
3. In solution in more or less heated water containing gases—the hydrothermal theory.

[1] J. H. L. Vogt: 'Silbererz,' etc., *Zeit. f. Prak. Geol.*, 1902, p. 8.

1. The Igneous Injection Theory.

The curious ideas advanced by A. Petzholdt[1] and J. Fournet[2], who ascribed the origin of mineral veins to injections of molten metalliferous matter coming from the remote depths of the earth, are now merely of historic interest.

The small veinlets of metallic sulphides formed artificially but unintentionally in the joints of an old furnace wall of the Muldner Works, near Freiberg, was supposed by B. von Cotta[3] to represent an example of a deposit formed according to this theory. These artificial veinlets are found in the gneiss of the furnace wall. The veins consist mainly of galena. The gneiss, moreover, was laterally impregnated with apparently perfectly isolated ore particles. Plattner, who also investigated these interesting artificial products, suggested very properly (it would seem) that sublimation rather than injection in the molten condition will probably account for their origin.

As will be shown farther on, the old injection theory has lately been resuscitated, being applied by Weinschenk to the pyrite deposit of Bodenmais.

2. The Sublimation Theory.

That certain ore deposits may be formed by sublimation is beyond doubt. Perfectly competent observers record the formation of hematite on lavas of recent age and in the craters of active volcanoes, often, indeed, within fissures. The following reactions explain the process:

$2FeCl_3 + 3\,H_2O$, both in the form of vapor,
give $Fe_2O_3 + 6HCl$.

This mode of origin of minerals through reactions of various *gases and vapors on each other* is designated, after Bunsen, by the term *pneumatolysis.*

Sublimation products having all the properties of natural ores are also sometimes formed during the roasting and smelting processes of our metallurgic furnaces; for example, artificial galenite, zinc-blende, realgar, etc. Finally, quite a number of other ores may be experimentally produced by sublimation, with exclusion of air, etc.

Durocher[4] was one of the principal champions of a general application of

[1] A. Petzholdt: 'Erdkunde.' Leipzig, 1840.

[2] J. Fournet: 'Vereinfachung der Lehre von den Gängen.' Freiberg, 1846. Translated from French into German by H. Müller.

[3] B. v. Cotta: 'Ueber Erzgänge in einer Flammofensohle.' Gangstudien, II. Freiberg, 1854, pp. 1–19.

[4] Durocher: 'Production artificielle, par voie sêche, des principaux minéraux contenus dans les gîtes métallifères.' *Comptes Rendus*, Vol. XXXII, 1851. p. 823; Vol. XLII, 1856, p. 850.

the sublimation theory to ore deposits. He thought that the inequality in the distribution of the ores in lodes could be best explained by assuming that they were deposited from gaseous currents. He tried to explain this theory experimentally by passing metallic vapors through heated glass tubes and thus producing deposits of various sulphidic ores.

A limited application of the sublimation theory to the veins of tin ore was made by A. Daubrée[1], and to this extent the theory still has many adherents. Daubrée pointed to the stability of tin fluoride at high temperatures, and assumed that the tin in this form rose from the depths of the granitic magma hearths during or immediately after the granitic eruption, and was accompanied by boron and fluorine compounds, for example, silicon fluoride, as well as gaseous chlorine and phosphorous compounds. He based this hypothesis on the extensive participation of fluorine, boron, chlorine and phosphorus in the composition of the gangues characteristic of the tin ore formation (page 200). As a further proof he produced cassiterite experimentally from volatile compounds. For this purpose, it is true, he did not use tin fluoride, but placed the entirely analogous tin chloride in a porcelain tube heated to white heat, through which he passed vapors of tin chloride and water. He actually obtained hydrogen chloride and small crystals of cassiterite. The process takes place according to the formula:

$$SnCl_4 + 2H_2O = 4H\,Cl + SnO_2.$$

In an entirely analogous way we may imagine:

$$SnF_4 + 2H_2O = 4HF + SnO_2.$$

A similar experiment gave:

$$TiCl_4 + H_2O = 4HCl + TiO_2$$

This last experiment led A. Daubrée to apply the theory of pneumatolysis also to the veins with titanium minerals such as are found, for example, in Dauphiny.

These ideas are strongly supported by the demonstration of the existence of corresponding metallic compounds in the fumaroles of existing volcanoes. Thus, according to A. Bergeat, the deposits of the fumaroles of the island of Vulcano were demonstrated by A. Cossa to contain almost all the elements characteristic of the tin deposits: boran and fluorine, besides lithium, tin, bismuth, copper, phosphorus and arsenic[2].

That the deposition of tin oxide is possible in nature in a purely aqueous way, even at ordinary temperature and under normal atmospheric pressure, is proved by the occurrence of fragments of stags' antlers in the tin ore placers of Cornwall, the organic substance in these fragments being, accord-

[1] A. Daubrée: 'Mém. sur le gisement, la constitution et l'origine des amas de minerai d'étain,' *Ann. des Mines*, 3d series, Vol. XX, 1841, p. 65.

[2] A. Bergeat: 'Die äolischen Inseln.' *Abh.* Akad., Munich, 1899, vol. XX. p. 193.

ing to J. H. Collins[1], partly replaced by tin oxide. Moreover, tin oxide occurs in many mineral waters, notably in the warm spring or Ajer Panas in Selangor on Malacca, where the siliceous sinter deposited by the spring contains, according to St. Meunier, the following substances:

Silicic acid	91.8	per cent.
Water	7.5	"
Tin oxide	0.5	"
Iron oxide	0.2	"

Notwithstanding these facts, all the phenomena discussed in treating of intrusive stocks of granite strongly support Daubrée's assumption of deposition by metalliferous, gaseous and vaporous exhalations during and immediately after the intrusion of the granitic magma. However, it would certainly be wrong to assume that the minerals of tin veins owed their origin to steam alone; the facts show it to be by a mixture of heated solutions and steam. We even think that the former must have been by far predominant. The formation of such vast tin deposits as, for example, those of Zinnwald, described previously, with their druse-lined cavities into which quartz crystals projected, some of them 30 centimeters long, distinctly indicates that there must have been a segregation from solutions. The numerous fluid inclusions in the topazes, tourmalines, quartzes, etc., of the tin ore lodes are also most naturally explained by this assumption.

It is shown elsewhere[2] that even after the formation of the tin-bearing impregnation fissures in the periphery of the granite stock of Zinnwald, later intrusions of the granitic magma took place, as clearly proven by the small veins of fine-grained, but slightly micaceous granite traversing those zwitter stringers in the quartz porphyry of Teplitz. This fact is also good ground for the belief that the development of the tin veins and impregnations was a direct accompaniment of the granite intrusion, and that, therefore, there is nothing opposed to the assumption of deposition by vaporous exhalations, together with overheated water given off by the hot magma.

In former times quicksilver deposits were believed to be due to sublimation as first advanced by Lasius[3]. The observations made on the quicksilver deposits of California (see p. 359) demonstrated the falsity of that theory for this class of ore deposits.

Deposition from sublimation was formerly suggested to explain the origin of certain gold veins. The occurrence of native arsenic, for example, on the lower side of rhodochrosite crystals, lying transverse to the selvage in

[1] J. H. Collins: 'Cornish Tin-Stones and Tin-Capels.' *Mineralog. Magaz.*, 1882, Vol. IV, p. 115.

[2] R. Beck: 'Einige Beob. im Gebiete der Altenberg-Zinnwalder Zinnerzlagerstätten,' *Zeit. f. Prak. Geol.*, 1896, p. 148.

[3] G. S. O. Lasius: 'Tagebuch einer Reise in die Gegend der Pfälzischen Quecksilberberge, in Born-Trebra.' Bergbaukunde, 1790, Vol. II, p. 353.

the gold veins of Nagyág, it was thought could be explained only by sublimation. Even Richthofen[1] assumed at that time that the gold veins in the propylites of Hungary and North America were formed by sublimation during a kind of solfatara activity in the eruptive centers of those regions. All the phenomena observed in this field favor the *hydrothermal theory,* which will now be discussed.

3. Hydrothermal Theory.

Freiberg has long been the radial point for the theory that mineral veins were produced essentially by deposition from rising thermal waters, the infiltration theory, as it was generally called in earlier days, the hydrothermal (or thermal) theory, as it is now universally and more fairly designated. The theory was first placed on a firm scientific basis through the work of F. C. von Beust, H. Müller, Th. Scheerer, B. von Cotta and A. W. Stelzner. It has since been carried all over the world by the numerous disciples of the two authors last named.

This theory originated, however, in France, where E. de Beaumont[2] was the first to advance detailed arguments in favor of the connection between mineral vein formation and the highly heated interior of the earth. According to him the lodes owe their origin to volcanic emanations, consisting of hot liquid injections, vaporous sublimations and watery infiltrations. From that time these views maintained their supremacy in France, and formed the key note of the great works by A. Daubrée, 'Les eaux souterraines aux époques anciennes,' and by E. Fuchs and L. De Launay, 'Traité des Gîtes Minéraux et Métallifères' (1893). This theory was also vigorously advocated by Th. Kjerulf and the Scandinavian school of geologists influenced by him. Its most positive expression, however, was doubtless given to it in the intensely suggestive work of F. Posepny[3], 'On the Genesis of Ore Deposits,' which first appeared in English in 1893. In North America the ground was prepared and ready for the acceptance of the most extreme view of the thermal theory as presented in Posepny's 'Genesis,' for at an early date J. S. Newberry[4] and other eminent economic geologists had declared themselves its adherents.

[1] F. v. Richthofen: 'Studien an den ungarisch-siebenbürgischen Trachytgebirgen.' *Jahrb.* d. k. k. geol. Reichsanst., 1860, p. 275.

[2] E. de Beaumont: 'Ueber die vulkanischen und metallischen Emanationen oder Ausströmungen,' translation in B. v. Cotta's Gangstudien I, Freiberg, 1850, p.p 329–436, out of *Bull.* de la Soc. Géol. de France, 2d Ser., Vol. IV, p. 1249, *et seq.*

[3] F. Posepny: 'On the Genesis of Ore-Deposits.' *Trans.* Am. Inst. Min. Eng., Chicago Meeting, 1893, Vol. XIII, p. 587, *et seq.* Second edition, with addition of other important works on this subject. New York City, 1902. Pub. by the Inst.

[4] J. S. Newberry: 'The Origin and Classification of Ore Deposits.' New York, 1880.

Its real victory may well be said to have begun only when A. W. Stelzner inflicted his destructive defeat of the lateral secretion theory as enunciated by Sandberger. In his last posthumous essay relating to this scientific battle Stelzner concluded with the following words:

"From all this it appears that the actually observed conditions can only be satisfactorily explained by the assumption that the solutions filling the fissures were not derived from the surface waters, but were spring water; that they were chemically and physically different at different places, and perhaps at different times, and that the substances deposited by them in vein fissures were for the most part brought up by them from the depths and only to a slight extent leached out of the rock bodies traversed by these fissures[1]."

This statement of the hydrothermal theory will form the basis for further discussion.

The hydrothermal theory in common with the lateral secretion theory maintains that the material of the veins, with the exception of wall rock introduced mechanically, was deposited from aqueous solutions. This supposition is entirely unobjectionable, since the solubility of all ore and gangue minerals in waters containing carbonic acid and other gases is an established fact, accepted since the famous investigations of G. Bischof. Furthermore, the formation of pseudomorphs and the structure of mineral crusts are important evidence on this point. The same testimony is given by the frequent inclusions of fluids in vein quartz and other vein minerals. Such liquids are even carried by the ores themselves, as may be observed in transparent zinc-blendes and proustite.

A great point in favor of the hydrothermal theory is the fact that the waters and deposits of existing hot springs contain both the metallic and non-metallic elements which compose the essential constituents of the ores of mineral veins. A careful and detailed summary of such occurrences has been given by G. Bischof[2], and since then our knowledge has been largely increased, as shown by the summaries of J. Roth[3] and L. De Launay[4]. From the rich fund of observed material on hand we will borrow only a few facts, taken mainly from De Launay's work:

It has long been known that numerous hot springs contain sulphur either in the form of hydrogen sulphide or as sulphates and sulphides of alkaline earths, and more rarely of metals, and carbonic acid in both the

[1] *Zeit. f. Prak. Geol.*, 1896, p. 412.

[2] G. Bischof: 'Chem. u. Phys. Geol.' 1st ed., 1847, Vol. II, p. 2079, *et seq.*; 2d ed., 1866, Vol. III, pp. 904—912.

[3] J. Roth: 'Chem. Geol.,' Vol. I, 1879, p. 564, *et seq.*

[4] L. De Launay: 'Recherche, Captage, et Aménagement des Sources Thermo Minerales,' Paris, 1899, p. 85 *et seq.*

free and combined condition. Chlorine compounds are frequently found. Bromine combined with alkalies is known to exist in the thermal springs of Nauheim, Iodine at Vichy. Fluorine exists in the springs of Carlsbad, Plombieres, Vichy and others; phosphoric acid in the two last named.

Arsenic is found abundantly in the hot waters of the Yellowstone Park geysers and hot springs (0.003 grams per liter or 0.3 grams sodium arseniate per gallon), and in the thermal springs of Bourboule (0.0155 grams of sodium arseniate to the liter). Boric acid is known from several geysers and hot springs of the Yellowstone Park, as well as in the thermal springs of Sulphur Bank and Steamboat Springs in western North America, as is described in greater detail in subsequent pages. Its presence has been demonstrated at Salies and in several other thermal springs of the Pyrenees; at Tarasp and Sanct Moritz; at Friedrichshall and Homburg, and in the hot waters of the copper mine of Boccheggiano (p. 428). From the springs of Salies boric salts were obtained. Not only is silica found in the boiling waters of true geysers, but it occurs in the thermal springs of Plombieres, Carlsbad and many other localities. Titanic acid is mentioned from the boiling springs of Pyrmony and from Carlsbad. Sodium, potassium, calcium, magnesium and aluminum are extensively distributed. Lithium is contained in the waters of Vichy, Bourboule and Ballardvale, and many other springs. To complete this list we will add that traces of rubidium and caesium occur in the spring waters of Carlsbad, Vichy, Bourbon and elsewhere. Barium and strontium are present, for example, in the springs of Ems (0.0028 grams per liter) and of Carlsbad. A spring near Lautenthal, in the Harz, flowing 40 liters per minute, deposited 2,000 kilograms of barite in the brief space of 3 to 5 years. Iron and manganese are present very often, the former sometimes in great abundance. Traces of chromium are contained in the deposits of the hot springs at Carlsbad. Nickel is known from Ronneby in Sweden, cobalt from Lamalon (Hérault), zinc from Pyrmont, tin from Kissingen and elsewhere, copper from Bruckenau, Rippoldsau and Sanct Moritz. Lead does not seem to have yet been proved with certainty. Traces of gold are mentioned from Carlsbad. Its presence in thermal springs is proved by a specimen of decayed wood in the hot springs of Taupo on New Zealand, in which Liversidge discovered gold-bearing pyrite and in the pyrite deposited in fissures in rhyolite by the waters of the Monarch Geyser, Yellowstone Park, as discovered by Weed. Antimony occurs at Pyrmont and Steamboat Springs, Nevada; quicksilver in several thermal springs in California (see later). Silver occurs in the deposits of the Boulder Hot Springs, Montana. Gold and silver to the value of $15 per ton occur in sinter of the Ohaeawai Hot Springs, New Zealand.

Still more conclusive evidence than this presence of metals in many thermal springs is afforded by the further fact that many thermal springs even now flow in mineral veins. This was first set forth in detail by Daubrée[1] and by Müller[2].

At Plombieres, in the southern Vosges, numerous mineral springs issue from the granite in a zone 220 meters long and 70 meters wide. The temperature of the hottest is 73° C., and that of the others only 15° to 30° C. Among their chemical constituents, which amount to but 0.03 grams per liter, potassium silicate predominates. When excavations were made in the granite about the so-called "soapy" springs in order to enclose them, several veins of quartz and fluorspar were traversed and the same minerals were found impregnating the adjoining granite, as well as the lower layers of variegated sandstone which overlie it. Besides the minerals named the veins also carried some barite, iron pyrite and red hematite. The thermal waters rise along the walls of these veins. That these deposits are still forming in fissures is proved by crystals of fluorspar in the midst of the Roman walls, as well as by a series of interesting newly formed minerals produced by reactions between the compounds contained in the thermal water and the ingredients of the concrete used by the Romans. In the cavities of the bricks bound together with lime mortar, zeolites, especially apophyllite and chabasite, have crystallized out, accompanied by opal and aragonite. A much greater variety of newly formed minerals was encountered, according to A. Daubrée[3], in cleaning out an old Roman well on a thermal fissure at Bourbonnes-les-Bains. The thermal water acting on accidentally introduced gold and silver coins, pieces of lead, bronze statuettes, iron objects, and the like, since their introduction in Roman time, had led to the segregation of quite a series of ores, such as galenite, phosgenite, anglesite and cerussite, as well as cuprite, chalcocite, chalcopyrite, bornite, tetrahedrite, atacamite, and finally iron pyrite and a siliceous oxidation product of iron.

Out of numerous examples tabulated by Müller a few may suffice:

According to H. Müller, the thermal springs of Wiesenbad and of Wolkenstein, in the vicinity of Annaberg, rise from drusy quartz lodes which in places carry barite. In the Churprinz, Friedrich August Erbstolln, at Grossschirma, north of Freiberg, barytic lead veins in biotite gneiss were formerly worked (see p. 258). In one, the Ludwig Spat, in 1821, about 160

[1] A. Daubrée: 'Mém. sur la relation des sources thermales de Plombières avec les filons métallifères,' etc. *Ann. d. Mines.* V. Ser., Vol. XIII, Paris, 1858, pp. 227–256.

[2] H. Müller: 'Ueber die Beziehungen zwischen Mineralquellen und Erzgängen im nördlichen Böhmen und in Sachsen.' B. v. Cotta's Gangstudien, III, Freiberg, 1860, pp. 261–309.

[3] A. Daubrée: 'Experimental Geologie,' Paris, 1879, pp. 71–102.

meters below the surface, a mineral spring was tapped having a temperature of 29.5° C., and rising in especial abundance at intersections of cross fissures. Chemical analyses showed it to be acid with sulphates of the alkaline earth and to hold free carbonic acid and to be almost entirely free from iron.

Mention may also be made of the thermal spring reported by F. Laube, having a temperature of 28° C., which was tapped at a depth of 331 m. (1,085 ft.) in 1864 in the Geschieber lode at Joachimsthal in the Bohemian Erzgebirge.

A very remarkable hot spring was tapped in 1901 in the copper vein of the Boccheggiano mine (see p. 267) near Massa Marittima, Tuscany. Its temperature was 40.6° C. According to an analysis by Fresenius, reported by the mine management, one liter of the hot water contained:

Sulphuric acid	0.3100 grams.
Silicic acid	0.0232
Boracic acid	0.0073
Chlorine	0.0179
Carbonic acid (combined with bases)	0.0771
Lime	0.2718
Magnesia	0.0271
Ferric oxide	0.0035
Potash	0.0288
Soda	0.0060
	0.7727

To refute these and other facts, F. Sandberger pointed out that most thermal springs leave deposits only on the earth's surface, but do not produce true quartz formations in their channels of exit. This objection is overthrown by the occurrence in western United States of hot springs which show deposits of metallic sulphides and other compounds in the fissures of active springs. The Ohaeawai Hot Springs of New Zealand are similar[1].

At Steamboat Springs, in Nevada (6 miles from the well-known Comstock Lode) the substratum is formed of granite covered by Juratrias beds, and is intruded by andesites and basalts. Carbonic acid and some hydrogen sulphide issue from the ground, and there are several thermal springs with a temperature of 75° C. (167° F.)

In the siliceous sinter of the basin of Steamboat Springs metallic sulphides are found. A piece of sinter colored red by metastibnite (Sb_2S_3) and weighing 3,403 grams contained:

Gold	0.0034 grams.	Silver	0.0012 grams.
HgS	0.0070 "	PbS	0.0720 "
Cu S	0.0424 "	Fe_2O_3	3.5924 "
$(Sb, As)_2S_3$	78.0308 grams.		

[1] A. P. Griffith: *Trans.* New Zealand Inst. Min. Eng., Vol. II, p. 88.

According to G. Becker, 10 liters of the thermal water of Steamboat Springs contained:

$FeCO_3$	0,0029 grams.	NaCl	14,1475 grams.
$MgCO_3$	0,0099 "	KCl	1,9735 "
$CaCO_3$	0,1577 "	Na_2SO_4	1,1147 "
$NaHCO_3$	2,9023 "	Li_2SO_4	0,5650 "
Na_2CO_3	0,4313 "	$Na_2Bo_4O_7$	3,1368 "
$Ca_3P_2O_8$	0,0137 "	$Na_2Si_4O_9$	3,9090 "
Al_2O_3	0,0025 "	Na_3SbS_3	0,0100 "
NaHS	1,1147 "	Na_3AsS_3	0,0866 "
nNa_2S, HgS			Traces.

A tunnel into the hillside at Steamboat Springs cut one of the older hot spring fissures at a depth of 50 feet below the surface. This fissure contained quartzose veinstone carrying crusts and coatings of cinnabar.

Recent excavations have shown that the waters are encrusting and cementing together the pebbles of the old stream gravels with pyrite and stibnite[1].

Equally weighty evidence is furnished by the phenomena seen in mines at Sulphur Bank, in the Coast Range of California[2]. The deposit was at first quarried for sulphur. At a shallow depth the sulphur gave out, but in its place rich cinnabar ores made their appearance, both in fissures and as an impregnation of the completely decomposed rock. This rock consisted of sandstones and slates, often comminuted into a breccia and covered by a basalt sheet. Hot waters and gases emerge from the cinnabar-bearing fissures and rendered mining so difficult that work had to be abandoned as the depth became greater. Besides cinnabar, pyrite and opal are also deposited by the thermal water. The deposit of silicic acid is found in all possible stages of hardening, from a gelatinous condition to that of chalcedony, and alternates with crusts of cinnabar and pyrite. The temperature of the water was 80° C. (176° F.) The chief constituents of the salts, which occur in extraordinary amounts, are chlorine compounds, borax and double carbonate of sodium. The gases given off and in part held in the water have the following composition: in 1,000 parts, 893 parts of CO_2, 2 parts of H_2S, 79 parts of CH_4, and 25N, besides traces of ammonia. The pyrite of the deposit contained small quantities of gold and copper.

Finally a most instructive case is that of the hot springs at Boulder, in Montana, described by Weed[3]. The fissures, some of which are still filled by hot water, contain deposits of chalcedony, jasper, quartz and calcite, as well as of stilbite. The springs deposit practically no surface sinters.

[1] W. Lindgren: 'The Occurrence of Stibnite at Steamboat Springs, Nev.,' *Bull* Am. Inst. Min. Eng. No. 2, March, 1905, p. 275.

[2] G. Becker: 'Quicksilver Ore Deposits of the Pacific Slopes.' *Monogr.* U. S. Geol. Survey, XIII, 1888.

[3] W. H. Weed: 'Mineral Vein Formation at Boulder Hot Springs, Montana.' 21st *Ann. Rep.* U. S. Geol. Survey, 1900, part II, pp. 227–255.

The granite alongside the veins is decomposed, the feldspars and quartz, hornblende and biotite having been altered to sericite and kaolin. Both this altered wall-rock and the vein filling contain small amounts of the precious metals, namely, up to 1.5 grams of gold and up to 12.4 grams of silver per ton.

A consideration of the thermal theory leads to the question: Where does the uprising thermal water come from? Is it derived from the atmospheric waters which have seeped down from the earth's surface (*vadose* region of F. Posepny) into the greatly heated depths (*profound* region of the same author), where it has gathered into large fissures, and returns, or is it the watery vapor given off by molten magmas?

A. Doubrée[1] thought that the first hypothesis answered this problem when he proved, by continuing the experiments of Jamin, that the force of capillary attraction accounted for the seeping in of atmospheric water along capillary fissures of rocks even down to the deep-seated zones of hot rocks and despite the counter pressure acting from below caused by the great development of heat in the deeper regions. That when this seepage water encountered fissures, to which the laws of capillarity do not apply, this now heated water returns to the surface in the form of a thermal spring or of vapor. He assumed that this may even explain explosions of steam and other volcanic phenomena. F. Posepny[2] applied the results of these experiments especially to the hydrothermal theory, and formulated his view in the following sentences:

"There is a descent of ground-water through the capillaries of the rock, even in the profound region. Having arrived at a certain depth it is probable that a lateral movement takes place toward the open channels. Having reached these it returns, ascending to the surface."

In opposition to this[3], Kemp has recently expressed doubts whether Daubrée's experiment can really be applied to the conditions in the interior of the earth, where the capillary force does not act against an empty space, as in the experiment. Kemp[4], moreover, pointed to the fact that in the deep works of several mines nothing is observed to indicate any general deep seepage of water in the rock; that these works even suffer from great dryness, as in the Calumet mine, Michigan, in the Adalbert shaft of Pribram, and in some deep works at Freiberg, and finally that many deep borings reach perfectly dry rocks. Ed. Suess[5], too, has recently expressed himself strongly

[1] 'Geologie Experimentale,' p. 236.
[2] 'Genesis of Ore Deposits,' p. 38.
[3] This and the four following paragraphs have been revised by the translator.
[4] 'Genesis of Ore Deposits,' p. 688, *Trans.* Am. Inst. Min. Eng., 1903.
[5] *The Engineering and Mining Journal*, Vol. LXXVI, 1903, pp. 8, 52.

against Daubrée's idea. The thermal springs, such as are concerned in the formation of most ore lodes, began merely by "juvenile springs," as they are called by that author, that is to say, springs which "rise from the depths of the globe as after-effects of volcanic activity and whose water comes to the light of day for the first time."

Whether this or the other view of the hydrothermal theory be adopted, it is certain that the mineral substances carried by hot water from below into vein fissures are in the main derived from the deeper regions of the earth. The water, in passing through those heated deep-seated regions, may have leached the mineral matter out of the rocks prevailing there, for it is well known how the solvent power of water is increased by high temperature.

This latter view accords with the *leaching out theories* of several American investigators, especially Emmons and Becker. They suggest that the material filling the veins was leached out by hot spring waters, not, indeed, from the immediate country rock of the ore-bearing fissures, but from rock masses situated farther away and in most cases at greater depth, especially from eruptive rocks[1]. Emmons discussed this view first with regard to the Leadville deposits[2]. Becker[3], writing of the thermal waters of Steamboat Springs and Sulphur Bank, assumed that the metallic compounds contained therein were leached out by water from the masses underlying the granite and also from the granite itself. H. Louis[4] justly remarks that there is no essential difference between this kind of a lateral secretion theory and the hydrothermal theory.

The clearest expression of this compromise form, so to speak, of the ascension or hydrothermal theory, was given by J. Le Conte. He opposed the view of F. Posepny that the thermal springs bring the metals up with them from the barysphere, that is to say, from the core of the earth, which, according to a plausible hypothesis[5], is very rich in heavy metals. Le Conte is of the opinion that the lower boundary of water circulation may possibly be reached at a depth of 8 or 10 miles. But in the thermosphere, which also has quite a high temperature, the springs, he thinks, would have sufficient opportunity to leach from the rocks the metallic compounds scattered through them in small amounts, and thus to concentrate them afterward in higher zones.

[1] For a clear statement of this theory see Emmons's Presidential Address, *Bull.* Geol. Soc. Amer., Vol. XVI, pp. 1–28.

[2] 'Genesis of Certain Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1886, Vol. XV, p. 125.

[3] 'Geology of the Quicksilver Deposits of the Pacific Slope,' *Monogr.* U. S. Geol. Surv., 1888, p. 449.

[4] H. Louis in Phillips-Louis treatise on 'Ore Deposits,' 1896, p. 136.

[5] This is affirmed by Vogt to be untenable. *Trans.* Am. Inst. Min. Eng., XXXI, p. 126.

An amplification and a very clear statement of Le Conte's ideas is given by Van Hise, whose work has already been cited. In a general way he attributes most ore deposits to *descending water,* giving it a much greater part in the deposition of ores than his predecessor just named. An excellent review of the entire subject is given by Emmons in his 'Theories of Ore Deposition Historically Considered[1].'

While we recognize that descending atmospheric water is an agent of great importance in the redeposition and further concentration of ores in the upper parts of mineral veins, yet we maintain that the original formation of most ore lodes is due to *thermal water rising from great depth. These thermal waters are believed to be the after-effects of Plutonic eruptions, such as the intrusion of granitic masses;* also of volcanic events in the narrower sense. This conviction is strongly supported by the close relation, so often pointed out in this work, between mineral veins and eruptive rocks—a relation finding more and more general recognition[2].

F. EPIGENETIC ORE DEPOSITS IN STRATIFIED ROCKS.

Exclusive of Veins.

It has been repeatedly pointed out in the preceding chapter that metalliferous waters not only formed deposits in fissures, but also penetrated in many instances into masses of stratified rocks and enriched them with ores. The manner of this mineralization is exceedingly varied.

In a number of instances the solutions simply filled the interspaces between the grains or crystalline constituents of rocks, completely saturating the entire strata and eventually leaving ore and non-metallic minerals in the pores. In most cases, however, the solution saturating the rock also attacked it chemically, etching and even dissolving certain constituents, whose place might thereupon be filled by particles of ore minerals. If the metalliferous solutions encounter readily soluble carbonate rocks, limestones or dolomites, calcareous slates, marls, etc., this replacement prevails to an important extent, being usually, it is true, accompanied by another process, namely, the filling of the pre-existing larger cavities in such rocks. The cases in which such fillings of cavities in limestone occur alone are probably quite rare, and are in such instances closely connected with the filling of vein fissures.

It is difficult to marshal this multitude of varied phenomena into any orderly arrangement, or to group them comprehensively, since sharp bound-

[1] *Bull.* Geol. Soc. Am., 1904, Vol. XVI, pp. 1–28.

[2] See Kemp: 'Rôle of the Igneous Rocks in the Formation of Veins,' *Trans.* Am. Inst. Min. Eng., Vol. XXXI, Feb., 1900. J. E. Spurr: 'A Consideration of Igneous Rocks,' etc. *Trans.* Am. Inst. Min. Eng., Vol. XXXII, Feb., 1902.

aries between the several categories do not, as a fact, exist in nature. Yet it is advisable, for practical reasons, that such a grouping be attempted, although it is realized that it can never be free from inconsistencies. In so doing we adopt as criteria for this separation into groups: 1st, the nature of the country rock; 2d, the shape of the deposits, at least to a certain extent, and accordingly establish the following divisions:

A. Ore deposits which are of distinctly stratum-like form, due essentially to an impregnation of non-calcareous rocks; briefly designated as *epigenetic orebodies.*

B. Ore deposits mostly in the form of pockets, masses, 'chambers' or 'chimneys,' formed essentially by the metasomatic replacement of calcareous rocks; in brief, *epigenetic ore stocks.*

C. Ore deposits mostly stock-like or tube-like in form, due essentially to a simple filling of pre-existing cavities; in brief, ore-bearing *cavity fillings.*

It will furthermore be convenient to separate and treat separately from the two first mentioned groups a series of deposits which do not indeed differ much from the others in form or structure, but differ greatly in mineralogic composition and genesis, namely, the *contact metamorphic deposits.* A more accurate characterization of them will be given later on.

A. EPIGENETIC ORE DEPOSITS.

(a) In the Crystalline Schists.

At the head of this group we put certain deposits whose ore is probably only in part of indigenous origin, and which thus represent a transition connecting this class with the syngenetic deposits already discussed. These deposits are furthermore distinguished by the presence of associated oxide and sulphide ores, while the great majority of this group of ore deposits contain, aside from the gossan, only sulphide ores.

Epigenetic Deposits of Oxides and Sulphides.

1. *The Ore Deposits of Schwarzenberg, Saxony.*

In the vicinity of Schwarzenberg, in the western Erzgebirge, a dome of gneiss (augengneiss) is the basal formation. This is overlain on all sides by a mantle of mica schist, overlain to the north in turn by conformable beds of Silurian age (phyllite) and terminated on the south by a displacement. The center of this great anticlinal is pierced by a granite stock seen at Galgenberg and Rackelmann, near Schwarzenberg. This intrusion is one of a series of about 20 granite stocks aligned from southeast to northwest. The line runs parallel to and just east of the edge of the great

Eibenstock-Neudeck 'massif' of granite, which has altered the rocks by contact metamorphism for a great distance from its borders. The orebodies occur intercalated in these contact-metamorphic mica-schists, being found in an upper and a lower horizon. As the rocks encircle the granite, the orebodies form two concentric ring-shaped zones around the gneiss dome.

The ore deposits always occur either in close connection with crystalline limestones and dolomites, together with a rock consisting essentially of light green pyroxene (salite) and actinolite (the rock being analogous to the Swedish skarn), or the ores form subordinate intercalations in the mica schists (for the most part garnetiferous muscovite schist and gneiss-mica schist). In exceptional cases, as at Schutzenhaus and Forstwald, near Breitenbrunn, a limestone bed ("graue Flösse") rich in siderite occurs between the ore-bearing actinolite bed and the limestone bed ("weisse Flösse").

The real substratum of the ore is always the salite-actinolite rock, which nearly always contains garnet, quartz (often as green prase filled with microscopic needles of actinolite), calcite, pistazite, chlorite, green mica and fluorite, more rarely brownspar, manganite, feldspar, axinite, tourmaline, titanite, apatite, vesuvianite and helvite.

Magnetite not infrequently occurs in layers or even in entire beds, alternating with the salite-actinolite-rock or the limestone, and rarely as a cement between corroded grains of salite and garnet. Some of the deposits were for a while worked as iron mines exclusively, the altered ore of the outcrop being composed of hematite and limonite.

A different condition prevails among orebodies of the other metals, and the deposits may be divided into two groups.

One group consists of pyritous-blendic-lead-deposits, whose general characters correspond to the veins of this class already described. In the present case the ore is found to be rich in chalcopyrite, and is sometimes accompanied by the silver cobalt ores. The other group comprises tin deposits.

The first group comprises iron pyrite as its most abundant ore, with zinc-blende (especially the dark-colored variety), argentiferous galena and chalcopyrite, to a less extent arsenical pyrite, arsenopyrite and pyrrhotite: very rarely rich silver ores, such as polybasite, argentite, ruby silver, native silver. The second group includes cassiterite (often in long columnar crystals), molybdenite, hematite and arsenical pyrite.

The minerals characteristic of the pyritous-blende-deposits are almost everywhere present when the beds carry any ores at all, but the proportions of the minerals vary. As the predominant mineral may be blende, replaced

deeper down by chalcopyrite or galenite, the deposits have been in the course of years worked for limonite, then as silver lead and afterwards as copper mines.

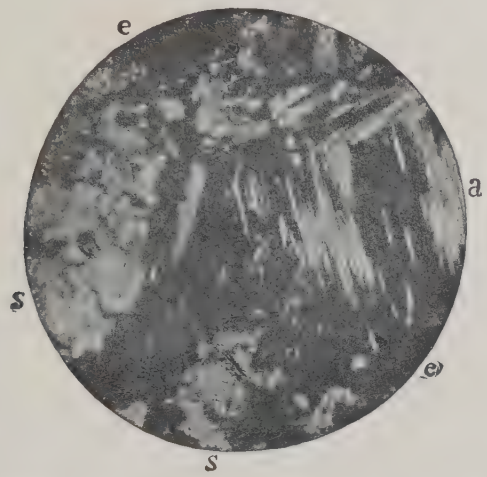


Fig. 191.—Thin section of an ore from the main bed of the Gelbe Birke mine, near Schwarzenberg.

S, salite (melacolite) in part transformed into *a*, actinolite; e, zinc-blende with chalcopyrite saturating a mat of actinolite fibers. (Enlarged 50 times.)

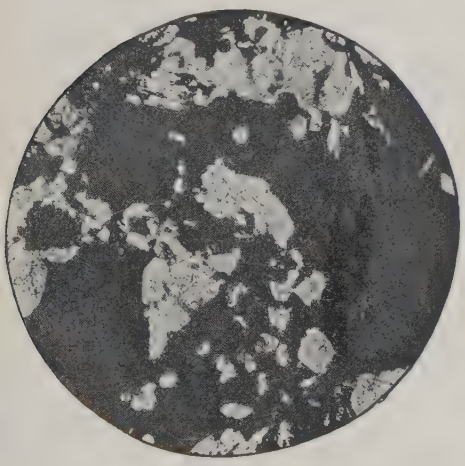


Fig. 192.—Thin section of an ore from the Fortuna mine near Breitenbrunn. Shows an aggregate of greenish yellow garnet partly replaced by arsenopyrite (black). (Enlarged 50 times.)

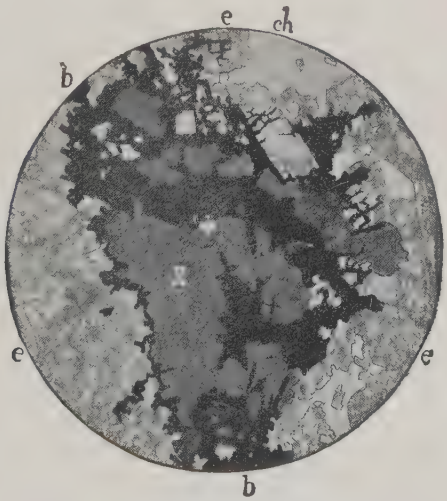


Fig. 193.—Thin section of an ore from Fünf Brüder Fundgrube at Antonsthal. e, epidote; ch, chlorite (peninite); z, yellowish brown zinc-blende; b, galenite. (Enlarged 50 times.)

Where the greenstone sheets, as they will be called for brevity, are the richest in ore they are always found to be strongly altered. The salite is more or less altered into actinolite, each gradation being seen in thin sections, and this product of alteration has been saturated with silica, producing prase and flint, and jaspery aggregates. In other cases epidote and a chlorite (mostly penninite) have been formed, or even the entire bed has been transformed into talcose and serpentinous aggregates. The metallic sulphides occur either in fine interspersed grains, in small stringers or pockets, or they form compact continuous bodies. The microscope shows that these ores and the quartz, wherever they occur with the silicates, are always the ingredients last segregated. The sulphides fill the interspaces between the metamorphic silicates, epidote (pistazite), actinolite and chlorite, but have also penetrated along fissures and cracks into the grains and crystals of garnet and salite, and quartz has also often been deposited similarly with them. The views of thin sections, Fig. 191 to 193, with their explanations, will elucidate what we have just said.

The ore is not uniformly distributed through the bed, but is often concentrated in pay streaks in the greenstone, the rest of the greenstone being almost barren. These streaks show an evident close connection with fissures cutting through the rock; indeed, these fissures also contain pyritous blendic lead ores, and in some cases also rich silver-cobalt ores, though never in workable amounts. Hence the mining work was not a simple extraction of a bed, for the workings followed the fissures in order to find the ore streaks. Thus, according to H. Müller's notes, in the Unverhofft Glück, a greenstone bed has been developed for 600 m. (1,968 ft.) in length and 120 m. (393 ft.) in depth, the workings following a vein 2 to 4 meters (6.5 to 13 ft.) or rarely 8 meters (26.2 ft.) thick, and dipping 45 to 55° west. In this mine the workable ores were all confined to the proximity of the transverse fissures, a great number of which were encountered in the field. The great orebody at Catarina shaft, for example, followed the intersection of the bed with the Hoffnung-Morgengang. The second nearest to the Hahnschacht lay at the intersection with a 'stehende' vein. In the Gelbe Birke and Hercules Frisch Glück mines, an ore bed, for the most part worked only for zinc-blende, contains a rich orebody 16 meters long and 40 centimeters thick, which has recently been followed, according to F. J. Fröbe, along the line of intersection of a narrow cross vein that is a few centimeters thick. This rich orebody consists mainly of chalcopyrite, with some blende and galenite. At the same time an extensive body of arsenical pyrite is exposed in the main ore bed of the Sanct Christoph mine, near Breitenbrunn. This plainly shows how the pyrite impregnation of the

greenstone stratum depends on the vein traversing it, a vein which also carries arsenical pyrite, as represented in Fig. 194.

A similar impregnation of wall rock with arsenopyrite from a vein may be observed in the Neue Silber-Hoffnung mine on the lower of the two magnetite deposits.

The cassiterite and the accompanying minerals of the tin formation, including, besides the above named ores, fluorite, chlorite, tourmaline and apatite, as gangues, does not occur in all the Schwarzenberg beds. Cassiterite occurs mainly in the mines at Breitenbrunn, where the Fortuna, Kaltwasser, Alte Grube and Sanct Christoph had been producing magnetite and cassiterite during the 16th and into the 17th centuries. In the 18th century more and more pyrite was found with increasing depth, and since 1781 pyrite alone has been produced, with very little tin ore. From the

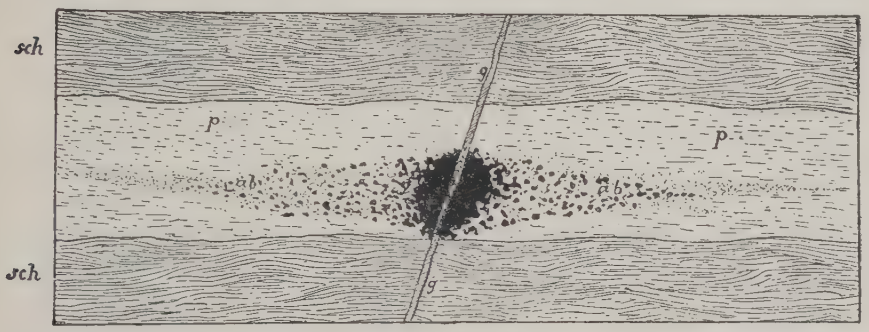


Fig. 194.—Longitudinal section of the main ore bed of the Sanct Christoph mine near Breitenbrunn.

sch, gneiss-mica-schist of the hanging-wall and foot-wall; p, pyroxene-actinolite rock, in the lower part, with layers of magnetite; g, Osterfest Spat lode; ab, impregnation with arsenopyrite, zincblende and some chalcopyrite, richest immediately next to the lode. (Length of the profile, 80 meters.)

old Sanct Christoph Zwitterbaue 100 to 200 quintals of tin were taken in some years. At Breitenbrunn both the hanging-wall and the bed itself were found to be traversed by stringers of tin ore, which also contained silver cobalt ore, probably in a secondary band or layer, as observed in many lodes of Johanngeorgenstadt.

There can hardly be a doubt that the minerals of the tin formation found in the Schwarzenberg beds also owe their existence to an impregnation from veins. H. Müller and Freiherr von Beust long ago recognized both the sulphides and the tin ores of the Schwarzenberg beds as later impregnations in the salite actinolite beds[1]. This was adopted by K. Dalmer, who,

[1] See theory that vapors and solutions, as an aftermath of intrusion, penetrate actinolitic and garnetiferous beds because of their porosity. 'Ore Deposits near Igneous Contacts.' W. H. Weed: *Trans.* Am. Inst. Min. Eng., October, 1902.

however, refers the phenomenon to the contact metamorphism so generally prevalent in that locality, while F. Schlach, without regard to structure or the distribution of the ores, decided in favor of a syngenetic view.

Mining in the Schwarzenberg district is now of slight commercial importance. In 1898 1,345 tons of magnetite, and small quantities of chalcopyrite, zinc-blende and arsenopyrite, were produced. Since then there has been a further decline. The Saxon Erzgebirge contains quite a number of deposits, analogous to those of Schwarzenberg, not only in the mica schist, but also in the gneiss and phyllite areas. Those that contain magnetite, pyrites and also cassiterite will be noted first.

Near the Geyer granite mass the mica schist contains the Hochmuth and Neues Glück ore bed, carrying magnetite, pyrite, blende, galena and tin ore; at Thum the phyllite contains the Silberzeche bed, carrying axinite.

At Kaffberg, near Goldne Höhe, northwest of Gottesgabe, the Breitenbrunn conditions are almost exactly repeated, with the difference that in the former place the ore-bearing greenstone strata are intercalated in the phyllite gneisses of the phyllite formation[1]. Similar occurrences are found at Johanngeorgenstadt.

Other deposits consist merely of magnetite and pyrite, blende and galenite, as, for example, the orebodies worked until 1807, mainly for copper ore, in the mica schist at Kupferhübel, near Kupferberg, in the Bohemian part of the Erzgebirge[2], and other numerous occurrences of that region, one of which has quite recently been reopened near Pressnitz for the extraction of magnetite. These deposits are found in various horizons of the crystalline schists, when the peculiar bed suitable for mineralization is present and fissures occur to serve as conduits. Granite intrusions are mostly though not always present in the vicinity, but it is quite possible, though not perfectly proven, that all these phenomena belong to contact metamorphism in the widest sense, as affirmed by K. Dalmer.

2. *The Orebodies in the Crystalline Schists of the Riesengebirge.*

On the south side of the Riesengebirge, the crystalline schists contain ore-bearing intercalations analagous to those of Schwarzenberg; thus, for example, according to H. von Festenberg-Packisch[3], in the fifties of the last century a bed of diopside rock approximating 2 m. thick was worked at

[1] K. Sternberger: *Zeitschrift* d. montan. Vereins im Erzgebites Joachimsthal, 1856. Nos. 10 and 11. Joh. Jokély: 'Zur Kenntniss der geol. Beschaffenh. des Egerer Kreises.' *Jahrb.* d. k. k. geol. Richsanst., 1857, p. 61 *et seq.* A. Sauer: 'Erl. zu Section Wiesenthal,' p. 43.

[2] A. Sauer: Erl. zu Section Kupferberg, 1882, p. 38

[3] H. v. Festenberg-Packisch: 'Der metall. Bergbau Niederschlesiens,' Vienna, 1881, p. 4.

Ober-Rochlitz. This contained large and small pockets of argentiferous blende, chalcopyrite, bornite, galenite and tetrahedrite. According to various older writings, summarized by B. von Cotta[1], a deposit formerly exposed from Ober-Rochlitz to Starkenbach is of special interest. Ore-bearing beds of diopside of great thickness occur there between mica schists and a crystalline limestone. The ores are mostly altered into secondary products. Reuss long since expressed the opinion that the ore impregnation was due to a quartz vein traversing the diopside[2] stratum and itself containing copper ores. At Spindelmuhl intercalations of hornblende schist carry arsenopyrite, iron pyrite, chalcopyrite, pyrrhotite and magnetite. In the Riesengrund, near the Schneekoppe, arsenopyrite and pyrrhotite occur in a layer up to two meters thick, and bodies of chalcopyrite are also known under a bed of limestone and garnet rock. At the Schatzlarloch, near Kleinaupa, the same ores are found, together with magnetite in a chloritic schist, crystalline limestone and a garnet diopside rock.

We may also provisionally include in this section the arsenopyrite and pyrite deposit of Reichenstein[3], although its genesis does not as yet appear quite clearly made out. At Reichenstein, near Glatz, in Prussian Silesia, the mica schists contain intercalations of crystalline limestone and of an augite-feldspar rock, the latter having undergone a profound alteration into serpentine masses (common and noble serpentines), tremolite and chlorite schists. At the largest of the mines, Reicher Trost, a thick serpentine mass has been exposed in contact with a limestone bed, the serpentine being connected with pyroxene feldspar rock, which has not yet been completely transformed. The bed has a maximum thickness of 40 m. (131 ft.) and has been traced to a distance of several hundred meters. The serpentine is the carrier of arsenopyrite, which, together with some magnetite, occurs disseminated through the rock, and also forms larger compact ore-bodies. The adjoining limestone, too, is traversed by veinlets of this ore-bearing dark-colored serpentine. The arsenopyrite is auriferous, so that originally only gold ores were mined, but, since the beginning of the last century, arsenic has been the chief product. The roasted arsenopyrite contains on an average 40 grams ($26.64) of gold per ton. Besides the above named ores, blende and galenite, carrying a silver and gold content, occur, as well as pyrrhotite, some chalcopyrite, bornite, pyrite and erythrite. Documents of as early a date as 1344 show that Reichenstein was a gold mining town. In 1900 the mines produced 3,530 tons of dressed arsenic ore.

[1] B. v. Cotta: 'Erzlagstätten,' II, p. 215.

[2] A lime-magnesia-pyroxene.

[3] R. B. Hare: 'Die Serpentin-Masse von Reichenstein,' etc. Breslau, 1879. F. Posepny: 'Goldvorkommen Böhmens.' *Arch. f. Prak. Geol.*, 1895, Vol. II, pp. 322–331. With bibliography.

There is a positively surprising resemblance of both mineralogic and geologic features between the Schwarzenberg (especially the Breitenbrunn) deposits on the one hand and those of Pitkäranta on the other.

3. *The Ore Deposits of Pitkäranta in Finland.*

Pitkäranta lies in the southeast part of Finland, on the northeast side of island-dotted Lake Ladoga. The outermost island has on it the famous monastery of Walamo. The mines are situated on the mainland close to the lake, in a gently undulating region abounding in rocky outcrops, or covered with marsh and scrubby forest. Farther away lie the mines of Huoponvaara at the northeast, Lupikko at the east and Heponselkä at the southeast, all belonging to the same group.

Up to the present time the best account of these deposits is the little monograph by Törnebohm[1]. A more extensive account is being prepared by Trüstedt.

The basal or bed rock in this region is a reddish granite gneiss, forming three dome-shaped masses. In the syncline between these three arches of gneiss is a series of conformable and younger crystalline schists, the lowest layer being a hornblende schist containing the orebodies, the uppermost layers being biotite gneisses and garnetiferous mica schists.

Recent mining developments show a difference[2] between a lower and an upper band of ore, each running perfectly parallel to and along the boundary of the granite gneiss.

The lower band consists mainly of a salite-garnet rock (locally called skarn), within which copper ores form subordinate masses. On the other hand, the ore band lying about 300 meters (984 ft.) above consists mainly of dolomitic limestones, containing pockets and layers of magnetite.

The younger crystalline schists are cut by numerous intrusions of granite rocks. The schists are cut off at Lake Nietjärvi and at Huoponvaara by the great Rappakivi granite mass. Moreover, pegmatites form veins and huge stocks, mainly in the lower ore band. The lower or main ore band has been opened since 1840 by a great number of small shafts. In the eastern mines it has a thickness of 3 to 4 meters, but increases gradually westward up to 20 meters (65.6 ft.), which, however, includes an intervening bed of hornblende gneiss. At the east it dips southward at an angle of but 20 to 30°, at the west at 60 to 70°. Immediately underlying it at the east is the granite gneiss; at the west a hornblende gneiss. Horn-

[1] A. E. Törnebohm: 'Pitkäranta malmfält.' *Geol. Fören. Förh.*, No. 137, Vol. XIII, part 4.

[2] From a brief communication kindly sent by Ingenieur Trüstedt.

blende gneiss immediately overlies it everywhere. The bed is not continuous downward, splitting up as shown in the deepest mine, the Omeljanoff IV shaft, in which at a depth of 100 meters it divides into several beds, that quickly wedge out, and between which there are pegmatitic masses intruded from below.

Its special composition is as follows: The true rock matrix, skarn, consists mainly of salite and garnet, the latter mineral predominating in the middle zone. This skarn is coarser-grained near the elongated and stretched druses which lie parallel to the schistosity and are filled with calcite, fluorite, quartz, garnet and various ores. The garnet often occurs in perfect crystals zonally built, and optically anomalous crystals of very diverse coloring. The ores consist of chalcopyrite, magnetite, cassiterite, to a less extent of zinc-blende, iron pyrite, more rarely yet of galenite, chalcocite, bornite and pyrrhotite. Occasional patches or grains of scheelite, molybdenite, native bismuth and bismuth telluride occur, and also secondary native copper.

Of all these ore minerals magnetite alone appears in the lower band under such conditions that it may be regarded as a primary constituent of the bed. It forms fine grained layers and lenses a few centimeters to several meters in thickness, sometimes enclosing druses with crystals of the ore, and with chlorite, calcite, xylotile and diopside. But when in the upper band we see the magnetite in distinct small veinlets[1] and stringers traversing the dolomitic limestone and the silicate rock, as was observed by Trüstedt in the limestone quarries Clara I, and the Herbert shaft, one doubts the primary nature even of this constituent.

The chalcopyrite in the lower band shows a decided preference for the diopside 'skarn,' where it fills the interspaces between the grains of salite, usually altered to chlorite and actinolite. The same is true of the blende and the other sulphides. The cassiterite was mainly concentrated in the tin mine (Omeljanoff II, III). It occurs in fine disseminated particles and in lumps, and not only in the skarn, but also alongside of it in the pegmatite, a feature that is also true of the chalcopyrite and the molybdenite. The cassiterite-bearing veinlets of the decomposed pegmatite cut through the feldspar intergrowths. The well-known needle tin (Nadelzinn) crystals occurs with calcite and quartz in druses in the skarn. Törnebohm regards the entire series of crystalline schists of the region as a metamorphic formation. According to him the skarn originated from beds of impure ferruginous limestone. Subsequently the cassiterite and its accompaniments, such as fluorite, scheelite and molybdenite, were introduced

[1] A. Lacroix: 'Melanite Carrying Veins of Magnetite,' *Guide*, Congrès Int. Geol., 1900, p. 12.

by pneumatolysis, and lastly chalcopyrite, iron pyrite, and the other sulphides. He lays stress upon the fact that tin crystals are found completely enclosed by iron pyrite and chalcopyrite, never the reverse. All these mineralizations took place as a sequel to the intrusion of the pegmatites, and perhaps also of the Rappakivi granite.

4. *Kallmora Silver Mine at Norberg, in Sweden*[1].

This seems the proper place in which to mention a peculiar ore deposit found at Kallmora Silfvergrufva, in the Norberg iron ore district, described previously.

The country rock is a fine-grained, well foliated biotite gneiss. In the beds immediately above and below the ore, the rock is either poor in feldspar or devoid of it, but contains in its place a light-colored pyroxene, some hornblende, garnet and cordierite. The structure is exceedingly suggestive of the mosaic structure of the contact metamorphic rocks about granitic intrusions. The cordierite, too, is encrusted with quartz granules in the same way as in the true contact metamorphic hornfels. A good deal of magnetite occurs in layers in this country rock. There is no doubt it is a primary constituent, for it often forms sharp crystals alongside of the quartz veins, and is often penetrated from all sides by quartz individuals. The case is quite different with the galenite, which is also found sometimes interspersed in the gneiss. This is a later immigrant filling the gaps between decomposed pyroxene grains. The bed, which is 3 to 5 m. (9.8 ft. to 16.4 ft.) thick, and dips almost vertically, is mainly a crystalline limestone, grading irregularly into a garnet pyroxene skarn rich in fluorite. In its upper part the skarn becomes subordinate, and the ores were found directly in the gneiss (the so-called granulite). The oxidic and sulphidic ores remain, on the whole, rather sharply separated, as shown by the cross-sections prepared by the owners. The oxide ores consist of magnetite and hematite, forming streaks and layers in both the upper and lower bands of gneiss, especially where it contains garnet and pyroxene, that is to say, where it becomes skarn-like. The sulphide ores form extensive bodies of galenite, with 0.015% silver (in sample at Freiberg) and smaller bodies of pyrite, chalcopyrite and arsenopyrite, and occur as isolated masses in the midst of limestone and skarn, or occasionally, as for example at the depth of 100 m. (328 ft.), replace the bed for its entire thickness. The fine crystalline galena predominates, but is accompanied by colorless or violet fluorite, calcite, and some garnet. A coarsely foliated variety of this ore also

[1] G. Nordenström: Mineralogiska notiser in *Geol. Fören. Förh.*, Vol. IV, No. 12, p. 340. A. Helland: 'Bergbeg, Anthracit og nogle andre kulholdige Mineralier fra Ertsleiesteder og Granitgange.' *Geol. Fören. Förh.*, 1874–75, p. 513. R. Beck: 'Ueber einige mittelschwedische Eisenerzlagerstätten.' *Zeit. f. Prak. Geol.*, 1899, p. 1.

occurs, forming stringers penetrating coarsely crystalline segregations of quartz in the garnet skarn. A later introduction of the precious metals is indicated by the occasional occurrence of distinct crusts. Thus blunt crystals of 'greasy' quartz occur in the garnet skarn, surrounded by a thin layer of chalcopyrite, and often penetrated by small stringers of this mineral. On one side of one of these quartz segregations, there is a large patch of coarsely crystalline galenite. In rare cases the ore contains secretions of calcite, with fluorite and chlorite, enclosing débris of clearly identifiable magnetite, in part as fine as dust. This shows that the primary magnetite layers were crushed before the introduction of the calcium carbonate and calcium fluorite, which cemented the powder. Equally important genetically is the presence of garnet fragments in the fluorite and sulphide ore mixture, garnet fragments being sometimes surrounded by coarse, foliated galenite, and being furthermore traversed by fine stringers of the ore. G. Nordenström also describes from Kallmora sessile crystals of magnetite, which thus would seem to occur here also as a new secondary formation.

In the upper part of the deposit the galenite ores are somewhat oxidized and friable, and hold stringers and bunches of calcite, with asphalt-like anthracite up to 500 c. c. The granules and lumps of anthracite are seen to be not only enclosed in the calcite, but are also penetrated by a network of calcite veinlets. This remarkable association is not unique, for asphalt-like masses also occur in iron ore at Moosgrufva and Kilgrufva.

From these observations it is seen that at Kallmora the magnetite and garnet seem to be older constituents, while galenite, chalcopyrite, arsenopyrite, fluorite, calcite and asphalt immigrated later, after faulting. The former is indigenous to the country rock in its present metamorphic condition, the latter guests in it.

The total output of lead ore from the Norberg mines from 1891 to 1895 was on an average 6.661 tons per year. The ores formerly smelted at Freiberg now go to Sala. Until a few years ago they were sent to the Freiberg furnaces.

5. *The Deposit of Schneeberg, near Sterzing.*

The Schwarzenberg and Pitkäranta deposits are closely related in character to a number of deposits in the Austrian Alps, particularly that of Schneeberg, near Sterzing, although the latter in turn presents many analogies with the deposits of Bodenmais and Broken Hill. An account of the Alpine deposits is introduced here, because the ores consist of sulphides together with magnetite.

The rocks about Schneeberg, south of Innesbruck in Tyrol[1], consist of mica schists, with garnet, staurolite, cordierite, feldspar and gneiss. In addition there are thin intercalations of amphibolites, calcite-muscovite schists, calcite-biotite schist, quartzite and dolomite.

The deposit is intercalated in the mica schists and varies greatly in thickness, its average being 4.26 feet (1.3 m.). Its length is 800 m., and it has been mined for 300 m. in depth. The ore consists of zinc-blende and argentiferous galenite, which, according to von Beust's estimate, exist in the proportions of 10 to 1, in a gangue of quartz and breunnerite. The accessory minerals comprise pyrrhotite, pyrite, arsenopyrite, chalcopyrite, boulangerite, argentite, tetrahedrite, native silver, as well as magnetite, menaccanite and limonite; with the following gangue minerals: calcite, dolomite, fluorite, apatite, garnet, actinolite, chlorite, biotite, muscovite, and finally, decomposition products of the ores.

The Schneeberg deposit was regarded by von Beust as a bedded vein; by Posepny as a metasomatic formation due to the replacement of an anhydrite bed; by von Elterlein as a lode.

That it is a bed of the character of the Schwarzenberg deposit, is borne out by the mineralogic composition. The following facts enumerated by von Elterlein favor the vein theory: (1) The symmetry, which is often pronounced in the succession of the various layers composing the deposit. (2) The fact that the stratification of the country rock is occasionally cut through. (3) The presence of a quartz stringer, and (4) the occurrence of cockade ores, that is to say, fragments of the country rock encrusted by layers of ore. Conceived as a lode, the deposit would belong to a variety of the pyritous-blende lead deposits, characterized by special gangues.

The Schneeberg mining industry began in the sixties of the 15th century, and was directed at first to the silver in the galenite. After an interval of idleness, work was resumed in the seventies of the 19th century, and the deposit is now worked solely for the rich zinc-blende ores, whose exploitation proved to be remunerative after the introduction of a magnetic method of dressing. The Schneeberg mine, at an elevation of 7,321 feet (2,232 m.) above the sea, is the highest mine in Europe since the close of the gold mine of the upper Rauris. Similar deposits described by Canaval[1] occur in Carinthia. Only a few of them can here be briefly mentioned.

[1] K. Frhr. v. Beust: 'Ueber die Erzlagerstätte vom Schneeberg,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1870, Vol. XX, part 4. *Idem:* 'Die Erzlagerst. vom Schneeberg,' etc. *Oesterr. Z.* f. B. u. H., 1871, p. 201. F. Posepny: 'Ueber die Lagerstätte am Schneeberg in Tirol.' *Oesterr. Z.* f. B. u. H., 1879, p. 106. A. v. Elterlein: 'Beiträge zur Kenntniss der Erzlagerstätte des Schneeberges,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1891, pp. 289–348.

[2] R. Canaval: 'Zur Kenntniss der Erzvorkommen des Lamnitz- und Wellathales in Kärnthen.' Carinthia, II, No. 5, 1898.

In the valleys of the Lamnits and the Wella, the prevailing crystalline schists contain pyrite beds 1 to 12 ft. (0.3 to 3.7 meters) thick, between a hornblende schist and an underlying garnet mica schist. The beds consist of pyrite mingled with quartz, pyrrhotite and chalcopyrite, zinc-blende, and some galenite. Uralite, tremolite, zoisite, biotite, fibrous hornblende, titanite, albite and calcite are also mentioned.

At the Kanappenstube, near Oberdrauburg, a deposit[1] is known which consists of pyrite, pyrrhotite and calcite, with subordinate arsenopyrite, galenite and zinc-blende in a gangue of quartz, albite, labradorite, muscovite, biotite, augite, epidote, zoisite, titanite, tremolite-like hornblende, rutile, ankerite, calcite and graphitic substances. The arsenopyrite contains 104 grains of gold per ton. A garnet-bearing pyrite bed also occurs at Lading[2].

6. *The Copper-bearing Sjangeli Schists.*

The remarkable copper ore deposits of Sjangeli, in Swedish Lapland, are placed provisionally in this class. They lie close to the Norwegian boundary, southeast of Torneå, and are as yet undeveloped. They consist of zoisite-bearing hornblende schists which carry bornite and chalcocite, together with some chalcopyrite, in the form of disseminated granules, streaks or small lenses, in part also in the form of stringers. These sulphidic ores are accompanied by magnetite. The geology of this region is described in a paper by W. Petersson[3].

(β) Epigenetic Deposits of Sulphidic Ores.

I. Zinc-blende Deposits.

1. *The Zinc-blende Deposits of Ammeberg, in Sweden.*

The zinc mines of Ammeberg[4] lie near the north end of Lake Vetter, in the Orebro district.

The steeply dipping beds of blende occur in a band of fine-grained, gray, biotite gneiss, with red fine-grained, biotite gneiss (Rödgranulit) on the

[1] R. Canaval: 'Zur Kenntniss der Erzvorkommen in der Umgebung von Irschen und Zwickenberg bei Oberdrauburg in Kärnthen.' *Jahrb.* d. naturh. Landesmus. f. Kärnthen, 1899, part 25.

[2] *Idem:* 'Ueber das Kiesvorkommen von Lading.' *Jahrb.* d. naturh. Mus. von Kärnthen, 1901, part 24.

[3] W. Petersson: 'Om de geologiska förh. i trakten omkring Sjangeli koppar-malmsfält i Norrbottens län.'

[4] B. Turley: 'Der Zinkbergbau der Altenberger Gesellschaft bei Ammeberg in Schweden.' *Berg u. Hütten. Zeit.*, 1866, p. 405 *et seq.* A. E. Törnebohm: 'Beskrivning till Bl. No. 7 af Geolog. Öfversigtskarta öfver Mellersta Sveriges Bergslag,' 1881, p. 31 *et seq.*

north and a coarse-grained biotite augengneiss[1] on the south. (See sketch-map, Fig. 195.) Minor bands of crystalline limestone occur in the steeply dipping gneisses, with two deposits of blende near by. Both these bands of zinc-blende conform to the abrupt folds and turns of the gneiss, both at Lake Trij and east and west of it. North of Lake Trij a stock of medium-grained granite traverses the schists, while in the eastern part of the field a mass of gabbro (gabbro diorite) insinuates itself more in the line of the strike. The northern deposit, with the Victoria and Lyck mines, is the least important. The other, the main deposit, is situated on the hanging side of the limestone, and has been opened in several shafts. This ore band can be traced continuously for 5 km. (3 m.), except where the granite massive at Lake Trij cuts through and interrupts it. It consists of lenticular bodies succeeding one another in a series, their thickness varying greatly, though in most cases it is 4 m. to 6 m. (13 ft. to 19.6 ft.), exceptionally 12 m. (39.3 ft.). The northern boundary plane (the hanging-wall of the mines) is against the gray, fine-grained gneiss, and is apt to be sharply developed, and the rock is readily detached from the ore. Close to the foot-wall, an intercalation of a handsomely stratified wollastonite rock, banded in cross fracture, sometimes appears.

In the open-cut close to Perier this intercalation is again succeeded by an ore bed about 40 meters thick, before the foot-wall is reached. The foot-wall is formed of a micaceous skarn, very rich in pyrrhotite, itself underlain by a light-colored, banded lime-silicate rock, consisting mainly of wollastonite, and enclosing layers of crystalline limestone. Next follows a fine-grained biotite gneiss, which in certain slightly micaceous layers closely resembles granulite. The ore bed itself also shows a peculiarly distinct bedded structure, the layers of ore alternating with barren or poor layers of wollastonite rock or fine-grained scaly gneiss (halleflinta). In certain cases some of the bands of the bed are greatly crinkled and twisted, while others close by show but feeble bends. The photograph of an ore specimen shown in Fig. 196 exhibits on a small scale the crinkling seen on a grand scale in the view at the top of the mines.

The deposit shows many pegmatitic masses intercalated in and alongside of the bed, mostly as bedded veins, sometimes as what appear to be entirely isolated lumps arranged more or less parallel to the stratification, but sometimes cutting across the bedding; thus between Vilain and Perier the ore bed is in one case completely cut off by a broad pegmatite mass. These pegmatites are rather coarse-grained and consist in the main of a microcline, colored green when exposed to the air, together with some quartz, and

[1] Augengneiss or porphyritic gneiss is one in which large eye-like kernels of orthoclase or quartz are dispersed through a finer matrix (Geikie, p. 321).

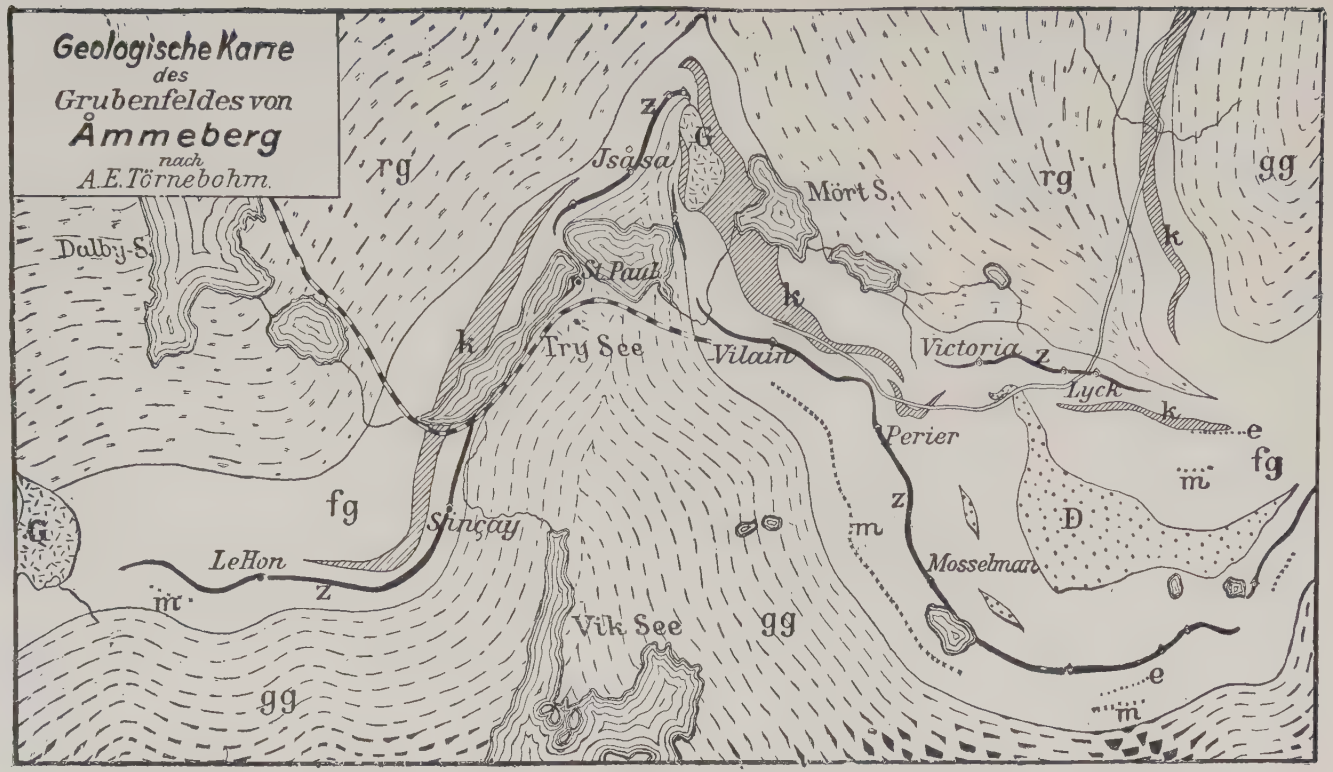


Fig. 195.—Geologic map of the Ammeberg mining district. (A. E. Tornebohm.)

Explanation of symbols: rg, fine-grained red gneiss; fg, fine-grained gray gneiss; gg, coarse-grained gray gneiss; k, limestone; e, eclogyte; G, granite; D, gabbro diorite; z, zinc-blende; m, pyrrhotite; ô, shaft.

sometimes they also contain black tourmaline. Furthermore, transverse veins of a fine-grained granite are distinctly observed in the country rock. These aplites and pegmatites are evidently connected genetically, since granite veins of this kind are found which show a transition to a coarse pegmatite in the center. Narrow calcite stringers, with small nests of asphalt, are occasionally found, and exhalations of inflammable hydrocarbons repeatedly took place on fissures. Very rarely minute cross fissures in the deposit contain sheets and rough nuggets of native silver.

The steep dip of the beds prevails in general to the lowest depths (down to 650 feet), save in the southernmost part of the field, where the dip lessens. For part of its course the main blende bed is accompanied by an

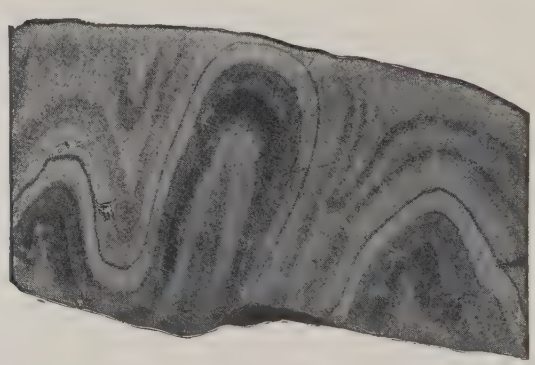


Fig. 196.—Strongly wrinkled portion of the blende layer with dark bands of gray gneiss. (One-half natural size.)

underlying perfectly parallel pyrrhotite layer, which is for the most part, it is true, merely a band of pyrite-impregnated gneiss. The mines have belonged to the Vieille Montaigne Company and have been vigorously worked since 1857. The ores are roasted at the mine, then shipped to Belgian zinc furnaces. From 1891 to 1895 there was produced an annual average of 23,535 tons of ore.

2 *The Zinc-blende Deposit of Långfallsgrufva, near Räfvåla, Sweden.*

The Långfalls mine[1] lies south of Lake Vessman, west of Ludvika, in the province of Dalarne. It belongs to the Saxberget Mining Company.

The deposit is 3 to 5 meters thick, outcropping beneath a glacial cover, as shown in the accompanying section, Fig. 197. It is conformably intercalated in crystalline schists which dip steeply south. The prevailing rock

[1] R. Beck: 'Ueber die Gesteine der Zinkblendelagerstätte Langfallsgrube.' Tschermak's *Min. u. petr. Mitth.*, Vol. XX, 1901, pp. 382–389.

is a fine-grained fissile biotite gneiss (granulite of the Swedish geologists), which is also found immediately underlying the deposit. In the hanging-wall, on the contrary, actinolitic rocks prevail, forming a band of about 40 meters (131 ft.) thick, in part strongly impregnated with blende and other ores. The orebody proper consists mainly of zinc-blende, and to a less extent of pyrrhotite, chalcopyrite, iron pyrite and argentiferous galenite. The distribution of these ingredients is not uniform, the galenite and pyrrhotite being accumulated in patches. At certain points the chalcopyrite is the most abundant ore. The ores merely form a more or less prominent filling amid bunches and individual needles of greenish gray monoclinic anthophyllite, which are evidently strongly corroded. Furthermore, the mixtures of ores contain grains of etched and corroded, partly decom-

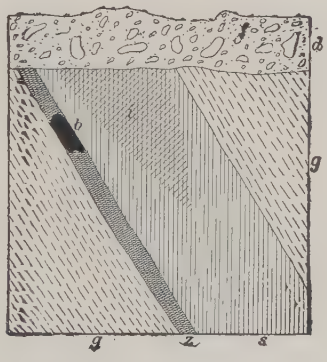


Fig. 197.—Section through the ore deposit of Langfallsgrufva near Räfvala.
s, actinolite rock which, at i, is impregnated with zinc-blende; z, zinc-blende deposit proper; b, orebody rich in galenite and pyrrhotite in the blende deposit; g, fine grained biotite gneiss, d, drift.

posed, polysynthetically twinned cordierite with cracks filled by ore, also grains of green translucent spinel, and some of a red-brown staurolite. Not infrequently the ore is found to contain coarse-grained, crystalline, pocket-shaped or lenticular segregations. These consist of quartz, orthoclase, plagioclase and cordierite of a blue or greenish variety, and green, translucent spinel, which encloses ore particles arranged in rows. The gray actinolitic rocks contain intercalated layers formed of a common green actinolite-hornblende. Pegmatites containing a green orthoclase also have been found in the midst of an orebody.

The mine was found in 1881 or 1882, the deposit having been located, despite its cover of forest, by magnetometric methods, and notwithstanding its comparatively small content of pyrrhotite. The production in the year 1897 was 600 tons of picked zinc-lead ore (stufferze);

11,000 tons of dressed ore and 109 tons of picked copper ore, while the mixture of actinolite impregnated with pyrrhotite and iron pyrite, and constituting about 4,000 tons of the output, is not put to any use.

In view of the great similarity in mineralogic composition, the description of the Långfallsgrufva deposit may be very appropriately followed by that of the long known occurrence of Bodenmais, although this is not a true zinc deposit, and hence does not really belong under the present heading.

II. The Pyrrhotite and Pyrite Deposits of the Silberberg at Bodenmais[1].

These deposits lie in a zone of biotite gneiss, distinguished by a great wealth of accessory minerals, such as garnet, cordierite, sillimanite, rhombic and monoclinic pyroxenes, zinc, spinel and menaccanite. E. Weinschenk regards these gneisses as contact metamorphic rocks, which owe their gneissoid condition to the intrusion of the granite mass near by and an injection with granitic magma. A similar view had previously been expressed by J. Lehmann. The rock is strongly folded, and in those parts that are particularly compressed it contains many irregular quartz aggregates, most of them lenticular. Orebodies occur only a few meters from the contact, the larger and richer ones being found at a greater distance. Toward the middle of the gneiss zone, which abuts against granite, the ores disappear entirely, according to the author last named.

The orebodies have the form of very irregular lenses, which often send branches into the country rock. In the upper bed their diameter not infrequently reaches 8 m. (26 ft.), with a length of 10 m. to 20 m. (33 ft. to 66 ft.) along the strike; sometimes, as in the great Barbara cut, the thickness reaches 16 m. (52 ft.) The deposits, as a rule, are found where the country rock is most disintegrated and is especially rich in quartz lenses. For that matter, they also occur toward the west, at horizons so diverse that the older division of the orebodies into three bands no longer appears justified.

The orebodies consist mainly of non-nickeliferous pyrrhotite, pyrite, chalcopyrite and zinc-blende. Some argentiferous galenite occurs, confined

[1] W. v. Gümbel: 'Geogn. Beschr. des Ostbayerischen Grenzgebirges,' 1868, pp. 548, 552. J. Lehmann: 'Entstehung der Altkrystallinen Schiefergesteine,' etc. Bonn, 1884. pp. 175–178. E. Weinschenk: 'Die Erzlagerstätten am Silberberg bei B.' *Glückauf*, 1898, No. 45, pp. 4–9. P. Wagner: 'Die Kieslagerstätten von Bodenmais.' *Naturw. Wochenschr.*, 1898, Vol. XIII, No. 25. E. Weinschenk: 'Der Silberberg bei Bodenmais.' *Zeit. f. Prak. Geol.*, 1900, pp. 65–71. *Idem*: 'Die Kieslagerstätte im Silberberg bei Bodenmais.' *Abh.* d. k. bayer. Ak. d.W., 2d ser., 1901, Vol. XXI, part II, pp. 349–410. K. Gruber: 'Der Schwefel- und Magnetkiesbergbau am Silberberge bei Bodenmais,' pp. 339–348.

to a very restricted area, and some cassiterite is present. The pyrrhotite and pyrite always predominate, but the amount of each mineral varies widely from place to place. The ore is compact, vugs being very rare. Minerals of secondary formation are found in sessile crystals, including zeolites, spessartite (manganese-alumina-garnet), vivianite, gypsum, barite, etc. There is no real gangue, but the mixture of minerals includes rounded, apparently etched grains of quartz which in many cases show secondary enlargement, also grains of cordierite, feldspar, andalusite, zinc-spinel, rhombic pyroxene and other constituents of the surrounding gneiss. These grains contain a core corresponding in composition to that of the same mineral when in the gneiss, but the accretions about the core contain, according to E. Weinschenk, numerous inclusions of pyrrhotite. The orebody sometimes shows symmetrically banded mineral crusts. The country rock next to the selvage is often rich in coarse-grained, gray-green feldspar. The ore deposit begins with a thin layer of galenite; next to it is a layer of zinc-blende, then one of pyrrhotite, and finally the central band or core of mixed sulphides. Toward the west the deposit holds occasional fragments of the country rock, surrounded by successive crusts in the order just named, forming cockade ores. Patches of country rock impregnated with ore, which are often found near the orebodies, exhibit a micro-breccia structure (cataclasis). The sulphides and the zinc-spinel have been deposited in the microscopic fissures and cracks of this rock. In such cases the chalcopyrite seems to be the last mineral to be formed.

The masses of vesicular, slaglike ore described by E. Weinschenk may be due to the secondary leaching out of some constituent, as has been observed in other deposits. Different observers have held very different theories of the genesis of the pyrite deposits of Bodenmais. The older authors as a rule believe the ores to have been formed with and as part of the country rock. The observations just mentioned show this view to be untenable. J. Lehmann thought that the ores were deposited in the cavities formed by the folding of the strata after the manner of the Australian saddle lodes. The invasion of the mineralizing solutions is supposed to be a direct consequence of the granite intrusion. E. Weinschenk, whose very minute investigations demonstrated the secondary introduction of the ores, is alone in his belief that the ores are due not to solutions, but to an intrusive molten material resulting from the granite intrusion. Such a theory is opposed to all observed facts concerning granite intrusions and the contact phenomena connected with them. A true melting of the country rock (in the metallurgic sense) did not occur at all, as proved by the lack of glass inclusions, etc. Moreover, deep-seated plutonic intrusions are not apt to show a slag-like structure, such as he finds in the ore.

To us it seems that the facts show a genesis entirely analogous to that given for Broken Hill (see next paragraph), namely, the introduction of ore-forming solutions into zones of mechanically loosened rock, and a partial metasomatic replacement of the rock by the ore minerals, with enlargement and regeneration of a part of the corroded or entirely dissolved original constituents. It also seems probable that these phenomena are genetically connected with the intrusion of the granite. As a matter of history, it may be mentioned that at Bodenmais mining was originally directed only toward the higher grade ores of the gossan, beginning as early as 1364. In 1463 pyrite was first mined from the Barbara and Gottesgabe mines, mainly for the manufacture of vitriol. The average annual production of the Silberberg deposit in recent years is 20 metric quintals. The ores are at present used for the manufacture of green vitriol and fine rouge.

III. Silver-Lead Deposits.

The Ore Deposits of Broken Hill, New South Wales[1].

Broken Hill lies in the Barrier Range, which rises from the Tertiary plain north of the lower Murray river, and has a north-south course.

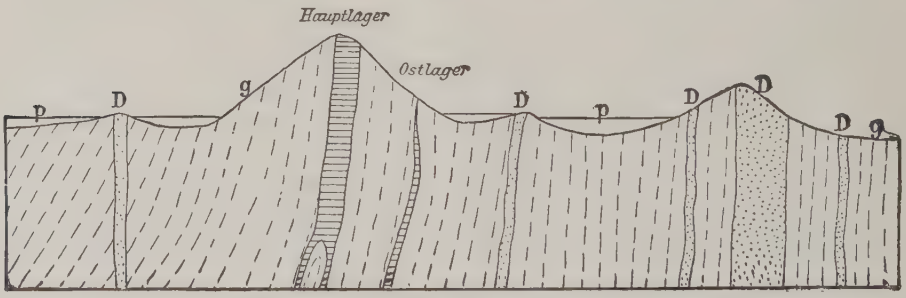


Fig. 198.—Section through the southern part of the Broken Hill deposit. (Jaquet.) g, gneisses, quartzites, and other crystalline schists; D, diorite; p, Pleistocene cover. (Hauptlager, main orebody; Ostlager, eastern ore-bed.)

This mountain area is of moderate elevation and is composed of crystalline schists, of undetermined age, intruded by masses of granite. The region is exceedingly arid and almost treeless, save in those valleys which occasionally carry water. Gneisses, quartzites and garnet rocks occur in steeply dipping strata in the immediate vicinity of Broken Hill and are traversed by numerous veins and stocks of dioritic rock, as shown in the section, Fig. 198.

[1] Jaquet: 'Geology of the Broken Hill Lode and Barrier Range Mineral Field.' *Mem.* Geol. Surv. of N. S. W., 1894. G. Eisfelder: 'Der Silber- Blei u. Zinkbergbau von Broken Hill,' *Berg u. Hütten. Zeit.*, 1898, No. 48–51. R. Beck: 'Bertrage zin Kenntniss von Broken Hill,' *Zeit. f. Prak. Geol.*, 1899, pp. 65–71.

The main lode of Broken Hill averages 59 feet (18 m.), but is sometimes 98 feet (30 m.) thick; it appears in cross-section as a stratum-like body, dividing below into two branches intercalated parallel to the banding of the garnetiferous biotite gneiss which adjoins it on both sides. The lode has been followed in the strike for a distance of 1.4 miles (2.4 kilometers), its outcrop forming a long, narrow, rocky line of hills. The mine workings show the rocks between the two branches of the vein to consist of quartz-garnet schists. A second unimportant orebody, lying at some distance east of the main lode, is intercalated in the garnetiferous gneisses.

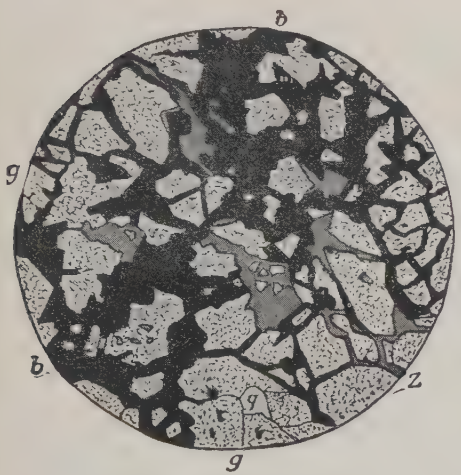


Fig. 199.—Micro-breccia of garnet rock with ores as cement. (Enlarged 50 times.) g, garnet; q, quartz; b, galenite; z, blende.

Fig. 200.—Garnet-rhodonite aggregate with immigrated ores. (Enlarged 50 times.) g, garnet; r, rhodonite; f, fluorite; b, galenite; z, blende; k, chalcopyrite.

The primary, unaltered ore of the Broken Hill lode is formed exclusively of argentiferous galenite and zinc-blende, in a gangue of quartz of a peculiar gray-blue tint, mixed with garnet, rhodonite and fluorite. This ore is now almost the sole product of the mine. The colorless or whitish fluorite usually escapes observation, being rarely in grains visible to the naked eye, or in stringer-like aggregates up to 3 centimeters wide. Less frequently chalcopyrite, pyrite, arsenopyrite and calcite are found.

Garnet is a constant and characteristic feature of the deposit. It forms innumerable tiny crystals in the midst of the ore and rarely, in larger, well developed crystals, shows numerous inclusions of sphalerite and galenite. The garnet, however, also occurs in the deposit in fragments of garnet rock, broken up into a breccia, galenite and blende furnishing the cement

between the fragments (Fig. 199), and lastly, as large fragments of garnet rock, sometimes surrounded by a fringe of secondary garnet. (See the figures by the author in the *Zeitschrift fur praktische Geologie.*) The rhodonite is not present in all parts of the deposit; it forms large reddish-brown aggregates, intergrown with garnet, or occurs in isolated, much corroded individuals, traversed by fine veinlets of blende and galenite, and imbedded in the midst of the sulphide ore (Fig. 200).

The contact rock between the orebody and the gneiss is remarkable. This is composed of a verdigris-colored orthoclase, a little plagioclase,

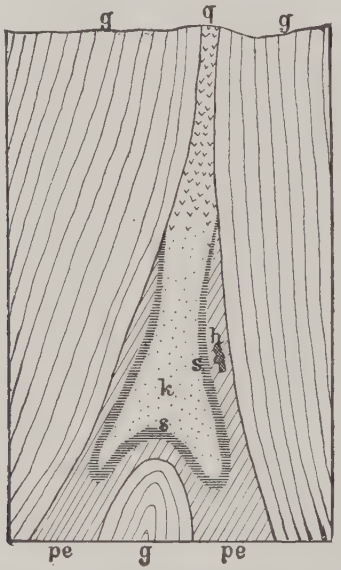


Fig. 201.—Ideal section showing the distribution of the ore in the upper part of the main lode of block 10. (Jaquet.)

g, garnetiferous biotite gneiss of the hanging-wall and foot-wall; pe, primary sulphidic ores; s, argentiferous secondary sulphidic ores; k, argentiferous kaolins; q, quartz and kaolin richly impregnated with oxides of iron and manganese.

scanty gray quartz, yellowish-red garnet, and dark mica. The wholly unstratified mass of the deposit shows, according to Jaquet, especially along the western boundary, protuberances which cut through the stratification of the gneiss. This feature may also be demonstrated on a small scale. Immediately adjoining the gneiss a specially garnetiferous zone with little ore nests is sometimes found, then a layer of quartz with comb structure, and finally the normal ore, enclosing great numbers of splintered quartz fragments.

The average content of the normal sulphide ore, according to Jaquet, is as follows:

Silver	0.15–11.19 kilograms per ton.
Lead	7 per cent to 50 per cent.
Zinc	14 " " 30 "

The gossan is of great economic and scientific significance, because of the presence of interesting secondary minerals and because it is exceedingly rich in silver (see section, Fig. 201).

The first alteration of the sulphide ores produces a cellular, honeycomb, spongy structure as a result of the leaching out of the silicates. In this way the leaching and removal of large rock fragments probably forms the drusy cavities occasionally met with in the orebody. These vugs are filled with fragments of quartz and garnet loosely cemented by argentiferous ore. Near the outcrop the metallic sulphides are more and more altered by decomposition, with an accompanying concentration of the silver at first into rich sulphidic silver ores, which are especially apt to impregnate garnet rock. In this usually narrow zone of secondary sulphide ores the amount of silver has occasionally been as high at 7.77 kilograms per ton. The explanation of this secondary formation of rich sulphides has already been given on page 378. Above these secondary ores is the great mass of gossan ore.

The deeper gossan ores consist of both very rich dry ores and lead carbonate ores. The former especially consist of kaolin completely impregnated with the chlorides, bromides and iodides of silver, together with native silver and decomposed garnet rocks, the whole carrying from 155 grams to 1.8 kilograms of silver per ton. The lead ore consists mainly of cerussite mingled with quartz and clay, impregnated with cerargyrite and native silver, as well as with manganiferous limonite, and usually containing 0.15 to 2.48 kilograms of silver per ton, and 20 to 60% of lead. Iodyrite, cerargyrite and embolite are often found in this part of the deposit in good crystals, also anglesite, stolzite, raspite, pyromorphite, smithsonite, fine specimens of native copper, malachite, azurite, cuprite, chrysocolla, and finally, in rare cases, the copper iodide called marshite.

Finally, the uppermost part of the deposit consists of ores formed of a mixture of limonite, psilomelane, quartz and clay, and containing many cavities, often giving it a slag-like appearance. In this also the rich secondary ores are found in individual crystals, especially in the druse cavities, from whose ceiling stalactites of psilomelane, limonite and calamine occasionally descend.

The genesis of the main Broken Hill lode is a very complicated problem. Pittman and Jaquet inferred from the structural conditions (inter-strati-

fication) that the Broken Hill orebody is primarily the result of a great parting of the strata about an anticlinal fold of the gneiss. When a crescent shaped cavity was thus formed in the folded rocks, large slabs of country rock must have peeled off, and since a grating movement between hanging-wall and foot-wall must have taken place, at least on a small scale, these detached fragments might be further comminuted. The space partly filled with rock débris might then be occupied by the ores and the accompanying gangues, such as quartz, fluorite, and the newly formed constituent, garnet. Though this view, in a general way, seems to us at present the most probable, yet from the description given it may be inferred that extensive metasomatic replacement of the adjacent schistose rock alongside of the large cavities helped in the formation of this deposit. It is this which has led us to exclude the Broken Hill deposit from the class of mineral veins and to describe it in its present place.

The first silver deposits of the Barrier Range to be discovered (1882) were the true mineral veins of Umberumberka, which led to the founding of Silverton. In 1883 an unsuccessful attempt was made to prospect for tin ore on the Broken Hill lode; it was not until 1884 that the first rich cerargyrite ores were found. In 1886 the town of Broken Hill was founded, which by 1889 numbered 17,000 inhabitants, but suffered greatly at first from drought and vexatious labor strikes. Numerous companies are at work on the enormous deposit. From 1889 to 1896 inclusive the Broken Hill Proprietary Company, the most important of the corporations, distributed $30,000,000 dividends, and produced 290,000 tons of lead, besides 2¼ million kilograms of silver. The entire district produced 70,000 tons of ore per month. The annual production of lead was 168,000 tons, or 27% of the production of the globe.

Besides the Broken Hill lodes other similar deposits are found in the Barrier Range. Thus the Pinnacle[1] mines, 14 kilometers southwest of the town of Broken Hill, work orebodies intercalated in the garnetiferous gneiss in the form of strata without sharp boundaries. These ores, judging by the specimens, are a mixture of argentiferous galenite and pyrrhotite, with some zinc-blende, and very little stibnite, in a gangue of quartz, garnet and a little brown, fibrous hornblende, resembling dufrenite. The receptacle for the deposition of the ores here was apparently an actinolite garnet rock.

A noteworthy fact is that in the Broken Hill Consols mine, distinct veins are worked which intersect the schistosity of the crystalline rocks and which contain quartz and garnet, besides galenite, zinc-blende, rich silver ores, siderite and calcite.

[1] Jaquet, *Mem.* Geol. Survey, N. S. W., 1894, p. 108.

IV. Copper Deposits and Iron Pyrite Deposits.

1. *Copper Deposits of Schmöllnitz, Upper Hungary*[1].

Schmöllnitz lies in a deep lateral branch of the Göllnitz valley, cut in steeply dipping beds of slates and talcose, chloritic and micaceous schists. The ore deposits are confined to a zone of gray clay slate about 360 meters thick, intercalated in a series of blackish, carbonaceous slates. Two varieties of deposits occur, the first lenticular pyrite stocks; the second stratiform impregnations, called 'stripes' (Streichen). Three of these zones of slate carrying pyrite and chalcopyrite impregnations (the upper, middle and lower 'stripes') have been followed downward to considerable depths. The pyrite stocks, called the upper, or hanging-wall, the lower, or foot-wall, and the Engelbert stocks wedge out at a shallow depth. The largest orebody is the lower pyrite stock, which extends 420 m. (1,377 ft.) along the strike, and for 42 m. (465 ft.) on the dip, with a thickness of 42 m. (138 ft.) All the 'stocks' consist of banded iron pyrite with narrow layers of bornite and pockets of copper pyrite. Near the boundaries of the stocks the ore contains intercalations of slate. The deposits are traversed by several fault fissures, a fault in the lower pyrite stock showing a throw of 20 m. (65 ft.) Near the pyrite stocks, the 'stripes' also yield valuable ore. Silver-bearing lead and cobalt ores also occur in small amounts in the Schmöllnitz deposits.

2. *Bedded Copper Deposits of Graslitz, in Bohemia*[2].

The pyrite beds of Grunberg and Eibenberg, near Graslitz, in the western Erzgebirge, some ten in number, are intercalated conformably in the gently inclined quartz-phyllites which dip west, and have on the east been transformed into spotted schists and andalusite mica rocks by the action of the Eibenstock tourmaline granite. The strata, which are 1.3 m. thick, represent, as shown by the confused internal stratification, zones of gliding or slipping in the phyllite rock that have been subsequently mineralized. The quartz and silicified, chloritized, phyllite filling contain pyrite and copper pyrite as the main ore minerals; also arsenopyrite, magnetite, bornite, galena, siderite and zinc-blende. An admixture of tourmaline is of genetic interest; this may increase in amount until typical tourmaline rock is

[1] A. Hauch: 'Schmöllnitzen Hüttenprocesse,' *Oesterr. Z.* f. B. u. H., 1860, pp. 269–271. B. v. Cotta: *Berg u. Hütten Zeit.*, 1861, p. 151. G. Faller: 'Die Kupferbergbau in Schmöllnitz.' *Berg u. Hütten Jahrb.* d. k. k. Osterr. Bergak, 1867, pp. 193–197.

[2] B. von Cotta: *Berg u. Hütten Zeit.*, 1869, pp. 82, 83. C. Gabert: 'Die geol. Umgebung von Graslitz,' *Jahrb.* d. k. k. geol. R., 1899, 4. Also *Zeit. f. Prak. Geol.*, 1901, pp. 140–144.

developed with inclusions of calcopyrite. Accordingly it is possible that the ore impregnation is here to be regarded as a contact effect. At the present time an effort is being made to resume mining on the ore bed at this place.

3. *The Pyrite Deposits of Chessy and Sain-Bel*[1] (*Rhone*).

The once famous pyrite deposit of Chessy, northwest of Lyon, is now worked out. This deposit and the group of pyrite deposits of Sain-Bel lying 10 km. (6 miles) to the south, which are still actively worked, are in rocks of different age and character, and belong to the same north-south zone.

At Chessy the following section, based on the old data of Raby, revised by de Launay, is useful:

1. Cupriferous pyrite deposit enclosed by pre-Cambrian pyritized hornblendic schists (yellow ore).

2. Masses of black oxidized copper ore (black ore) and other oxidized copper ores (gray ore) in a zone of decomposed rock, which separates the schists just noted from the Rhaetic sandstone that adjoins them along a nearly vertical fault fissure.

3. Orebodies of cuprite and native copper in the red clay filling of the fault (red ore): from this ore the well known pseudomorphs of malachite after cuprite are derived.

4. Stringers, concretions and geodes of a finely crystalline azurite found in the Rhaetic sandstones and clays close to the fault and underlying lower Liassic limestone (blue ore).

The orebodies No. 2 and 4 are probably secondary products resulting from the destruction of older pyritic masses, such as No. 1.

The pyrite beds of Sain-Bel, east of the Brevenne, may be grouped into a northern and a southern field. Only the latter is worked at present, 320,000 tons of very pure pyrite being mined each year.

According to De Launay, the ore forms great lenses enclosed in hornblendic and chloritic schists. These lenses are grouped in a series or train 2 km. (1.2 miles) long. The great vein of the south field is one of the largest pyrite bodies of the entire world, being 600 m. (1,968 ft.) long, and 44 m. (144 ft.) in maximum thickness (at a depth of 166 m. or 544 ft.) This single lens has thus far yielded about 5,000,000 tons of ore. It consists of dense, unstratified pyrite, with a very slight amount of quartz. Other lenses, such as the western lens of St. Antoine, sometimes also contain chalcopyrite and zinc-blende. The copper ore is highly siliceous and

[1] L. DeLaunay: 'Die Schwefelkieslagerstätte von Sain-Bel,' *Zeit. f. Prak. Geol.*, 1901, pp. 161–170. Consult also v. Cotta, Erzlagerstätten II, 1861, p. 421.

the ore banded. Numerous fault slips occur between the pyrite body and the schists lying parallel to the contact. Eruptive rocks are entirely lacking.

4. *The Copper Deposit of Falun, Sweden.*

The well known copper deposit of Falun is situated close to the town on the north side of the lake of the same name, in southern Dalarne.

Careful investigations of this vast orebody were begun at a very early date, being aided by the well managed platting system, which was begun in the seventeenth century. Indeed, there is a mine map in the form of a horizonal projection on the scale of 1:500, by Olof Hansson Swart, dated 1629. Modern geologic knowledge of the Falun mine is given in the splendid monograph by A. E. Ternebohm[1], from which the following description is taken.

The country rocks in which the deposit occurs consist chiefly of fine-grained biotite gneisses, often very poor in mica, which are called granulite by Ternebohm; there are also medium-grained gray gneisses and granite gneisses, besides mica schists, quarzites, hornblende schists, granular limestones and garnet-hornblende rocks (skarn).

The deposit has a foot-wall of gray, more or less micaceous quartzite, that occurs as a thick intercalation in the gray gneiss. Besides the grains of the dominant quartz, this foot-wall rock carries biotite, cordierite, as well as scanty amounts of falunite, andalusite, magnetite, actinolite and anthophyllite. Certain stock-like bodies of this quartzite, rather sharply defined and limited by barren rock, contain varying amounts of disseminated chalcopyrite, with associated pyrrhotite, iron pyrite and sometimes also a little zinc-blende. The ore of this quality, the so-called 'hard' ore (hard-malm), constituting about two-thirds of the entire output, contains on an average 5 to 6% copper. The distribution of the ore in the quartzite is as follows: in the gray, greasy-lustrous quartzite mass, nests and stringers of the ore lie in quite irregular arrangement. The larger bodies have a breccia-like structure, more or less rounded fragments of quartzite occurring imbedded in the pyrite as in a cement. Under the microscope the finer particles of ore show no definite genetic succession. They enclose one another in all possible combinations, and are, moreover, found both in the quartz grains and more abundantly between them. At times, however, minute veinlets extend from the larger chalcopyrite grains into adjoining quartz grains. Hence Ternebohm concludes that the material for the present sulphide ores must have existed in the deposits before metamorphic

[1] A. E. Ternebohm: 'Om Falu Grufvas Geologi.' (On the geology of Falu mine.) Geol. Fören. i Stockholm Förhandl., Vol. XV, part 7, 1893.

processes changed it to the ore-bearing quartzite of to-day. The breccia-like and vein-like formations occurring at times in the hard ore are of secondary origin, a result of subsequent pressure, such as is common in the rocks of that locality.

Besides these masses of ore-impregnated quartzite, ore is largely extracted from stock-like bodies of compact pyrites, more briefly called pyrite stocks. The ore of these bodies is called soft ore, "blotmalm," and contains an average of 2 to 3% copper. These stocks are also really masses of quartzite impregnated with pyrite, though the impregnation differs from that of the 'hard' ore both in quantity and quality. Moreover, transitions from one variety to the other are found in the so-called 'half-hard' ores, which on examination under the microscope still show all the normal ingredients of the gray quartzite.

The composition of the compact pyrite masses varies. The main varieties are: quartzose, calcareous and actinolite-pyrite ores. The quartz-pyrite ore is decidedly predominant. It is essentially a granular-crystalline mixture of iron pyrite and quartz with accessory cordierite, anthophyllite magnetite, copper pyrite, pyrrhotite, zinc-blende and in rare cases galena. For genetic considerations it is especially noteworthy that the pyrite often occurs in small crystals as inclusions, not only in the quartz, but also in the cordierite and anthophyllite. The other sulphides frequently constitute the cementing material between the grains of iron pyrite. A breccia-like structure also sometimes occurs in the 'soft' ore, in which case fragments of pyrite are enclosed by quartz, whose grains in their turn harbor minute crystals of iron pyrite. Hence the inference is that after dynamic forces had formed the breccia, a chemical regeneration and re-crystallization of the ingredients of the ore took place.

The calcspar ore is evidently a product of impregnation from limestone deposits, such as occur in this part of the mountain. The actinolite-pyrite ore, on the other hand, seems to have resulted from the pyritization of a *skarn* (granular-limestone and garnet-hornblende rocks).

Taken together the Falun pyrite-stocks form a rather irregular mass, whose core appears to be the Storgrufva stock, while to the southeast the Källorts stock, the Mans-Nils stock and the Drottning stock adjoin, and toward the west the Schultz stock and the Kräftklo stock are developed in the Luise mine. The central or Storgrufva stock, the largest of all, is 200 meters in diameter and tapers downward.

The various pyrite stocks are almost completely surrounded by so-called 'skölar.' By a 'sköl' the Falun miners understand the same thing that in the Harz is called a 'ruschel,' that is to say, a system of parallel fissures, filled with crushed and chemically altered material from the walls. This

material varies in composition with the nature of the adjoining rock; thus at Falun chlorite, talc and amphibole skölar are distinguished, adjoining the corresponding rocks. These skölar have for the most part a crescentic course, alternately uniting and separating.

These fissures, filled with friction products, sometimes also contain ores 'sköl malmer,' having proved, in fact, the bearers of the richest ores. Thus the richest orebody ever known at Falun was found in the Knipps sköl. It consisted of dense, perfectly pure copper pyrite, with intergrown cubes of iron pyrite. Such finds, however, always occurred only in the upper workings, which in itself points to a secondary origin.

Since October, 1881, when free gold was discovered in Falun ore by a boy, special gold ores are also extracted, a slight gold content (2 to 3 gm. per ton) having been previously recognized in the ordinary copper ore. The gold is found in delicate, white quartz strings, which at certain points occur in clusters in the hard ore, always in company with a seleniferous galeno-bismuthite. The ordinary 'selenmalm,' as the gold ore without visible gold is called, contains 10 to 30 gm. of gold (10 gm.=0.3 oz.=$6) to the ton. The richer gold ore, in which the gold is perceived even with the naked eye, may contain as much as 100 or even 300 gm. per ton ($66 to $198. The richest gold orebodies were found in the neighborhood of a much disturbed section called Mencka Vecket (Mencka fold), particularly where diorite dikes occur in the hard ore[1].

A few remarks may be added concerning these and other eruptive dikes in the Falun mine. At many points the quartzite is cut by felsite porphyry dikes, which ordinarily appear to be 'mixed' dikes, inasmuch as along each contact thin sheets of a badly altered dioritic rock accompany the main acid body of the dike. Ternebohm attributes them to different eruptions. Since recent discussion ascribes a simultaneous origin to such formations, the possibility of this genetic development is also to be kept in mind. These 'mixed' dikes, like the bedded schists, are jammed, folded and dislocated in all manner of ways, and this is especially the case with a number of narrow, independent dikes of diorite. Whole sections of such dikes have thus been torn entirely out of their connections and have been kneaded into entirely isolated lumps.

Falu Grufva is the oldest and most important mine of all Sweden[2]. Mining operations may there be traced back to the year 1220, and documents, dated as early as 1288, speak of the "Stora Kopperberget" (large copper mountain), as the mine is called. According to tradition, a herds-

[1] G. Nordenstrom: 'Fynd of gediget guld i, Falu grufra.' Geol. Fören, Förhandl., Vol. VI, p. 59.

[2] Th. Witt: 'Nagra tekniska och ekonomiska uppgifter rörande Falu Grufva.' Falun, 1896.

man discovered the reddish outcrop of the pyrite by noticing that a goat, in rolling on the ground, made a red-colored pit. For many years Falun was worked by a company with 1,200 shares, belonging for the most part to the crown. Since 1800 this has been changed into a stock company, called the Stora Kopparbergs Bergslags Aktiebolag. The great cavity called Stöten, under which mining is in part carried on by overhead stoping, was formed in 1687 by the collapse of extensive excavations. A well known incident is that of a miner named Mats Israelsson, who in 1670 was killed in the Mårdskin shaft, and whose body was found fifty years later preserved by vitriolized mine water.

The average yearly output of the Falun mine during the last decade was 400 tons of copper, 200 kilograms of silver (derived from silver-bearing blende and galena), as well as 80 to 90 kilograms of gold. The copper production in former times was magnificent, especially in the seventeenth century. About 1651 it amounted to 3,066 tons. The total output of copper is estimated at 500,000 tons, besides 15 tons silver and 1 ton gold. By means of this rich revenue, Gustav Adolf defrayed most of the cost of his campaigns.

5. *The Pyrite Beds of Norway*[1].

In four districts of Norway pyrite beds are found, which are worked for copper: (1) on the west coast of southern Norway, especially on the outlying islands; among them the well known but abandoned Vigsnäs mine, also a series of mines on Bömmelö and Veraldsö; (2) the small mines at Grimel, on the west coast of Grimeli, central Norway; (3) Trondjem district, especially the Storvarts, Kongen and Mug mines near Röros and the mines at Meraker and in the Foldal; (4) in the Sulitelma region in Nordland, north of the Arctic circle.

These deposits consist of iron pyrite with an admixture of copper pyrite. The ore contains on an average 2.5 to 3% copper. In rare instances zinc-blende and some other sulphidic ores appear, such as pyrrhotite, galena and arsenopyrite. The non-metallic minerals include quartz, which often occurs filling the entire orebody, hornblende, mica (mostly magnesium mica), diopside, garnet, more rarely feldspar, epidote, titanite, chlorite and talc, also fluorspar. Particularly noteworthy is the occurrence of numerous crystals of tourmaline in the pyrite of Vigsnäs.

The deposits form more or less lenticular masses conformably inter-

[1] A. Helland: 'Forekomster af Kise i Norge,' Christiania, 1873. J. H. L. Vogt: 'Salten og Ranen,' 1890–91, with review of literature, p. 157. H. Reusch: 'Bömmelöen og Karmöen,' 1888 (Vigsnäs). A. W. Stelzner: 'Die Sulitelma Gruben in nordl. Norwegen,' Freiberg, 1891. J. H. L. Vogt: 'Ueber die Kies lagerstätten vom Typus Röros,' etc., *Zeit. f. Prak. Geol.*, 1894, p. 41. O. Nordenskjöld: 'Om Bossmo Grufvors Geologi,' Geol. Fören Förh., Stockholm, 1895, Vol. XVII, part 5.

calated in the country rock. The latter consists of schists, mica schists, phyllites, fibrous schists (Carbonschiefer, containing concretions arranged in the form of sheaves), quartz schists, chlorite schists, all affected by regional metamorphism, with certain bands which, according to H. Reusch (Bömmelöen og Karmöen, 1888) at Bömmelö and Stordö and elsewhere, contain various easily recognizable fossils such as *Halysites catenularia, Favosites,* etc., and hence are of Silurian age.

It is a remarkable fact that the pyrite beds within these Paleozoic strata only occur where masses of saussurite-gabbro are found.

The lenses are for the most part but a few meters in thickness, rarely attaining 20 meters, but, on the other hand, while continuing but a short distance in the strike, they may usually be traced long distances in the dip. Sometimes they have the shape of true 'ore pods' (long, narrow lenses of

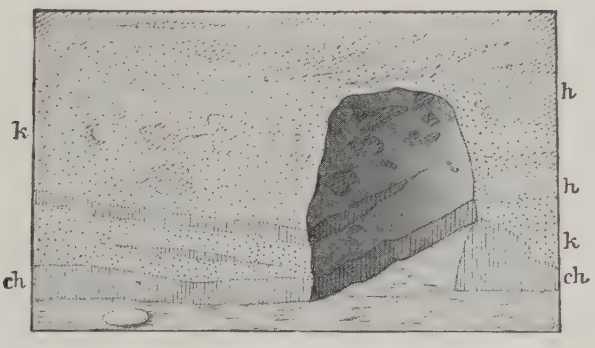


Fig. 202.—Outcrop of the pyrite bed of Mons Peter Uren. (Stelzner.)
h, hornblende schist; ch, chloritic schist; k, pyrite with inclusions of hornblende schist. (Thickness of bed 4 meters.)

ore, of uniform breadth and thickness) (see also pages 51 and 147). This pod-shaped form of deposit may be best illustrated by the example of the Mug mine at Röros, where the pyrite occurs in flat bands of phyllite, with a thickness of only 1 m. to 3 m. (3.2 to 9.8 feet), and a breadth of 100 m. to 150 m. (328 ft. to 492 ft.), while it is traceable to a depth of 1,050 m. (3,444 ft.) In the Storvarts mine, at the same locality, the corresponding figures are 1 m. to 3 m. (3.2 ft. to 9.8 ft.), 150 m. to 350 m. (494 ft. to 1,148 ft.) and 1,350 m. (4,428 ft.)

The contact between ore and country rock is often sharp, but there often is a transition zone, consisting of a schist with many conformably intercalated pyrite patches. The orebody in cross-section at times shows a banding parallel to the walls resulting from the presence of layers of somewhat different textures of ore.

Despite the general conformity of the orebodies with the schists, they occasionally, according to Vogt, cut across the banding or foliation of the country rock, as may be observed at times on the faces of the orebodies, while fragments of ore also occur in the schist, as appears from the section, Fig. 202. This figure also shows included schist fragments in the pyrite mass, and layers of schist intercalated parallel to the pyrite.

The entire mass of rock is at times strongly folded and compressed. This is particularly well shown by the large isolated iron pyrite crystals imbedded in the country rock, which are greatly deformed and have streaked and furrowed faces.

At times it looks as if the pyrite had been segregated only during the folding process, since it is found in special abundance at the points of flexure. In other cases again, pyrite layers take part in the most delicate folds, and hence must have taken part in the dynamic processes.

Very commonly striated surfaces and slickensides may be observed in the immediate vicinity of the pyrite bodies.

Finally, it is to be noted that pyrite beds quite similar to those described have sometimes been observed on slickensides in the midst of saussurite gabbro.

The saussurite gabbros, which have been mentioned several times, are now universally regarded as strongly compressed and dynamically altered intrusive masses of originally normal gabbros. In these rocks, the basic lime-soda-feldspar is completely replaced by saussurite, that is to say, a mixture of zoisite with albite. These gabbros also contain, instead of the diallage, hornblende in the form of smaragdite, as well as actinolite, chlorite, some garnet and rutile.

Concerning the origin of the Norwegian deposits and others of similar character, opinions are not yet settled. The view advocated by Stelzner and Klockmann, that the pyrite layers are sedimentary formations, still has adherents. This theory rests essentially on the fact of conformity, and an observed banding parallel to the stratification. It assumes that mineral solutions derived from the destruction of older ore deposits were precipitated by reduction through organic substances, in quiet parts of the sea, but it furnishes no explanation whatever of the constant association of the pyrite beds with the saussurite gabbros.

Vogt, on the other hand, thinks that the pyrite masses were formed from solutions forced into the schists along slip planes, following parallel planes of schistosity, the process being the result of gabbro intrusions and accompanying dynamo-metamorphism. As a good example of an analogous formation, he refers to the ore beds found in the contact areas about the intrusive masses of granite in the Christiania region, and he lays great

stress on the fact that the walls of the pyrite bodies may occasionally be seen to cut across the schist, and on the occurrence of pyrite on slip joints and fractures in the gabbro itself, as at Storhusmandsberget, in Meraker. He imagines the infiltration of the solutions to have taken place under such great hydrostatic pressure as to overcome the pressure of folding, which otherwise must have filled the cavities with materials squeezed in during the flexure.

In 1896 Röros produced 20,000 tons of smelting ore and 16,300 tons of pyrite for export, and had a net copper output of about 600 tons. Sulitelma produced 40,000 to 45,000 tons of copper ore, namely, 9,000 tons of smelting ore and 31,000 tons of pyrite for export. The net copper output was about 400 tons. The copper production of all Norway for 1902 was 4,638 tons.

6. *The Pyrite Beds of Ducktown, in Tennessee*[1].

The Ducktown district lies in the extreme southeast corner of Tennessee, in a part of the Allegheny mountain region formed of folded metamorphic crystalline schists composing part of the Ocoee formation, which is probably of pre-Cambrian age. The deposits form lenticular orebodies, 3 m. to 120 m. (10 ft. to 393 ft.) thick, arranged along three parallel principal lines of fracturing. The deposits are intercalated in thinly foliated micaceous schists, varying in dip from 50° to vertical. Where the outer walls of the orebody can be followed closely, it is found that in many cases they are fault planes intersecting the plane of schistosity at a slight angle.

The unaltered ores, found at a depth of 20 to 100 ft., consist of a mixture of pyrrhotite, with chalcopyrite and pyrite in lesser amounts, together with quartz, calcite, actinolite and zoisite. Zinc-blende and galena occur in very small amounts. These ores form either very rich impregnations of the micaceous or hornblende schists, as in the East Tennessee mine, or they form great lenses of solid ore and are composed of bands varying from a mere film to thick masses. The rich ores contain over 7.5% copper, but the ores average about 1.88% as mined. The magnetic pyrite contains little if any copper, the chalcopyrite being the copper carrier. In the compact ore masses splinters of mica schist occur as layers and various non-metallic minerals, notably zoisite, actinolite and garnet, occur with calcspar and quartz. The actinolite (evidently derived, according to Henrich, from a

[1] H. Credner: 'Die Kupfererzlagerstätten von Ducktown,' *Berg u. Hütten Zeit.*, 1867, pp. 8–10. A. F. Wendt: 'The Pyrites Deposits of the Alleghanies.' School of Mines *Quarterly*, 1886, Vol. VII. Carl Henrich: 'The Ducktown Ore Deposits,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, pp. 173–245. W. H. Weed: 'Types of Southern Copper Deposits,' *Trans.* Am. Inst. Min. Eng., 1900, Vol. XXI. J. F. Kemp: 'The Deposits of Copper Ores at Ducktown, Tenn.' *Trans.* Am. Inst. Min Eng., 1901.

pyroxene) forms netted aggregates filled with ore. The garnet crystals, too, are seamed by the ores, while the quartz was segregated simultaneously with the ores. The quartz also fills thin, flat, cross fissures (floors) in the beds.

Above the primary sulphide ores there was a zone of rich, black ore, the "black copper zone" varying from 0.6 to 2.4 meters thick. This consisted mainly of black copper glance, with sulphates of iron and copper, and, nearer the surface, of oxidized ores, viz., cuprite, malachite, azurite, etc., in nodules and druses, also native copper in sheets and bunches, and rarely cuproplumbite.

The black copper zone, for which the mines were first worked, is overlain by an iron gossan, 5 to 24 meters thick, consisting of sandy, scoriaceous, dense, spongy or hematitic brown iron ore, which in places formed prominent exposures.

Kemp shows the Ducktown rocks to be shales and sandstones altered by regional metamorphism into micaceous and quartzitic schists. The orebody may be, as suggested by Henrich, an altered and replaced hornblendic dike made schistose and impregnated with ores. From the association of the minerals among themselves Henrich infers that pyrrhotite and chalcopyrite were the first to be introduced, with a later introduction of the other sulphides and the quartz.

From existing remains it is inferred that the prehistoric mound-builders smelted oxidic ores in Tennessee. In 1850 the first mine, Hiwassee, was discovered. In 1853 the new area produced 808 tons of ore, with an average of 28% copper. Two companies are now operating in the district and the aggregate production for 1903 was 13,855,612 pounds copper.

Similar deposits occur in central Vermont at Copperfield and South Strafford[1]. Also at Ore Knob, Tenn. In Guerrero, Mexico, at La Dicha mine, forty miles northeast of Acapulco, a similar deposit occurs in schists. The ore consists of pyrrhotite and chalcopyrite, and is traceable for over a mile, 7,000 feet being actually exposed by development, with a thickness of 12 to 80 feet. (R. T. Hill.)

V. Cobalt Fahlbands.

1. *The Cobalt Fahlbands of Skuterud and Snarum, in Norway*[2].

The cobalt ore deposits of Skuterud and Snarum lie in the parish of

[1] W. H. Weed: *Bull.* 226, U. S. Geol. Survey, 1903, p. 189.

[2] The most important works are: J. F. L. Hausmann: 'Reise durch Skandinavien,' 1812, Vol. II, pp. 69–91. K. F. Böbert: 'Ueber die Analogie der Glanzkobalt-lagers bei Skuterud und bei Vena,' Karsten's *Archiv.*, 1832, Vol. IV, pp. 280–284. *Idem*: 'Ueber das Modumer Blaufarbenwork in Norwegen,' 1846, Vol. XXI, pp. 207–214. H. Müller: Note in manuscript, 1857. Kjerulf: 'Geol. d. sudl. Norwegens,' Translation by Gurlitt, 1880, p. 323.

Modum, in southern Norway, southwest of Tyrifjord. The country rock of the region consists of the uniformly vertical beds of crystalline Thelemarken slates, strata probably of Paleozoic age, altered by regional metamorphism. These are in the main underlain, in the area of the cobalt fahlbands, by medium-grained, very fissile biotite gneisses, characterized by an abundance of microline and sillimanite, and frequently showing a hornfels structure; subordinate intercalations occur of muscovite gneisses, various kinds of quartzite, amphibolite (mostly garnetiferous), biotite schist, salite rock and anthophyllitic and gedritic rocks. The amphibolites, which are abundant in the immediate vicinity of the cobalt deposits, form bands which it is true are mostly conformable to the schists, but do occasionally show a transverse strike; they are evidently metamorphosed gabbros and diabases. Numerous veins and irregular intrusive masses of pegmatite are also noticeable.

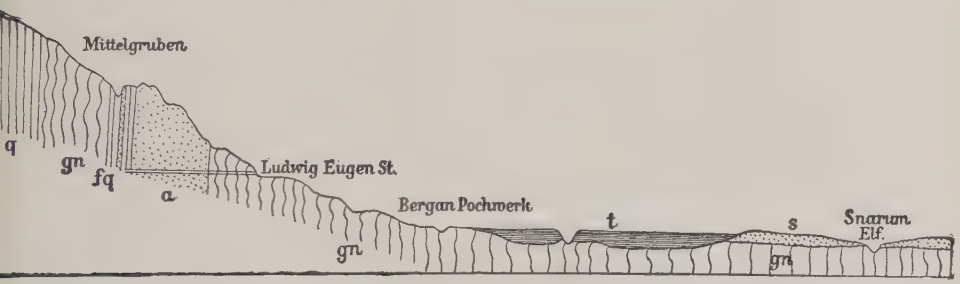


Fig. 203.—Section through the cobalt fahlbands of Skuterud.

gn, biotite gneisses, rich in sillimanite and microcline; q, quartzite; fq, fahlband quartzite, a garnet amphibolite; t, late glacial clays with fossils (*Arca glacialis* Sars); s, glacial sands and gravels.

Of the many fahlbands, only the largest is as yet of economic importance. This one is several hundred meters wide and 10 km. (6 miles) long, and runs north and south along the west side of the Simoa valley through a mountainous and mostly wooded region, from Muggerud near Skuterud northward to the region of Korsbön Höfe, near Snarum. Though a slight amount of cobalt is found in the rocks almost everywhere along this zone, which is two hundred meters wide and many miles long, yet only a few points were found rich enough in ore to work. Mines existed at Skuterud, farther north at Saastad, and finally at Devigkollen, near Svartefjeld, at Svendbye and Heggeback. A second but small cobalt fahlband of no economic importance runs along the opposite side of the valley, past the Snarum church.

The general geologic conditions of the Skuterud mines are shown in the cross-section, Fig. 203.

These cobaltiferous fahlbands are members of the complex of crystalline schists. They follow the general strike, and usually also the dip of the gneisses, and contain disseminated cobaltic and other ores. The impregnation is most marked in a light-colored, finely granulated quartzite. This fahlband quartzite contains, besides the predominant quartz, much brown mica, and is penetrated by numerous crystals of brown tourmaline, salite granules, fibers of anthophyllite[1], rutile, zircon, graphite and metallic sulphides. Certain bands of the quartzite are especially rich in cobalt ore, and in this case the rock contains a larger amount of salite or gray-green actinolite or anthophyllite, as well as plagioclase. Cobalt ores were also found associated with a granular-crystalline or coarsely radial salite rock, containing some plagioclase, quartz and brown tourmaline; this rock appears to be secondarily transformed into an anthophyllite rock.

The most important of the disseminated cobalt minerals is cobalt glance. It is usually found in well formed crystals, included in the quartz and other minerals that form the fahlband quartzite, but also occurs within the garnets of the micaceous outer layers of the amphibolites. The cobaltite is accompanied by small amounts of arsenopyrite, chalcopyrite and pyrrhotite. The two last named minerals sometimes envelop the cobalt glance, but themselves occur as inclusions in the tourmaline and other minerals of the fahlband. Furthermore, chalcopyrite of a later generation also occurs in the interspaces of the salite rock. In rare cases pyrrhotite is accompanied by molybdenite. No veins carrying cobalt ores are known in this area. Several small quartz-calcspar veins, which occur in the fahlband zone and contain pyrite, copper pyrite and galena, are evidently of younger formation, and have nothing to do with the genesis of the cobalt rocks.

The disseminated cobalt minerals are unevenly distributed in the fahlbands. Especially rich portions are found within the workable bands, rich pay streaks which are usually only 10-20 cm., rarely up to 0.5 m. thick. They commonly consist of a mixture of quartz, actinolite, mica and the metallic sulphides, but sometimes contain considerable masses of almost pure, compact ore. The orebody sometimes cuts across the schist at an acute angle with the dip of the rock, though the strike is the same.

As a rule the rock carries but a small amount of ore. From records made in 1840, Böbert infers that the ore-bearing fahlband masses then being worked yielded an average of 3% of millable ore, which itself in turn yielded about 3% of cobalt concentrates.

The genesis of these deposits is still in doubt, but it is probable that the fahlband rocks were cobalt-bearing before their regional metamorphism.

[1] Orthorhombic hornblende, $(Mg_9Fe)\ SiO_3$.

The cobalt mines in Modum parish were discovered in 1772, and until 1813 were the property of the Crown. In time when the price of cobalt was high, they were vigorously worked. In 1838-39, according to Böbert, 3,106 centners of cobalt concentrates were obtained. Toward the end of the forties, the most important mines passed into the possession of the Saxon Bluing Works, a private company.

The description of the cobaltiferous fahlbands of Norway applies almost exactly to those of Vena near Askersund on Lake Wetter in Sweden, deposits which, because of their lower percentage of cobalt, have long been idle.

There is a resemblance between the cobalt deposits of Skuterud and those of Tunaberg in Södermannland in Sweden[1]. The cobaltite and the chalcopyrite occur in grains scattered through crystalline dolomitic limestone rather than micaceous schists. In this case, too, no conjecture can be expressed regarding their genesis[2].

2. *The Cobalt Deposits of Dashkessan in the Caucasus.*

The cobalt deposits of the Caucasus are of quite a different kind from those of the cobalt fahlbands of Norway. They resemble quite closely the ore deposits of Schwarzenberg in composition and may be regarded as a cobalt-bearing variety of that type.

The Dashkessan cobalt deposit[3] outcrops on the east slope of the Katschkar-Tschai valley, about 6 miles west of Elisabethpol, in the Armenian mountain region, south of the main range of the Caucasus and the Kura river. The mines lie about 300 m. (984 ft.) above the floor of the valley and 5,000 to 5,575 ft. above the sea. While granite rocks are said to underlie most of the Katschkar-Tschai valley, the following conditions prevail at the mines:

The ore deposit dips gently, not over 50°, and quite regularly to the southeast, and the same dip prevails in the overlying and underlying strata. The stratigraphic series, from above downward, is as follows:

4. A reddish or dirty gray-green, decomposed porphyrite, forming the outcrop; in part transformed into a very fine-grained aggregate of epidote and garnet.

[1] Erdmann: 'Beskrifning öfver Tunabergs Socken,' Stockholm, 1849. Durocher: 'Observations sur les gîtes métallifères de la Suède et de la Norvêge,' *Ann. des Mines*, 1849, Vol. XV, p. 329.

[2] The mineralogically similar fahlbands of Kongberg, which are impregnated with pyrite, pyrrhotite, chalcopyrite, zinc-blende and galena, are described, together with the silver-veins of that place, on p. 275.

[3] A. Bernoulli: *Zeit.* d. D. G. G., 1867, Vol. XIX, p. 14. See also paper by G. Rose, same journal, 1868, p. 233.

3. The cobalt bed proper, on an average 0.2 m. (8 in.) thick.

2. A layer of magnetic iron ore, over 1.8 m. (6 ft.) thick.

1. A highly decomposed, light gray porphyrite, exceedingly rich in CaO and Na_2O.

The layer of magnetic iron consists mainly of finely crystalline magnetite, rarely showing large crystals of magnetite, and containing garnet, epidote, actinolite, quartz, chalcopyrite, zinc-blende and hematite; quartz, completely interwoven with hornblende spicules, and resembling the prase of Schwarzenberg, occurs mixed through the ore. The hematite forms large sheets or radial pseudomorphs after actinolite. Drusy quartz with hematite, small magnetite crystals and yellowish-green epidote occur, especially in the lower part, where they are associated with coarse calcite. Near the top the magnetite layer often shows an admixture of partly serpentinized, light greenish-yellow mineral, which proves to be a salite or a diopside.

This serpentine, together with green hornblende, chlorite, epidote, garnet and a prase-like quartz netted with actinolite spicules, forms the real matrix of the cobalt ore. Where this mass is specially rich in serpentine, it is called by the local miners pipestone, "chibush dash," because pipe heads may be carved from it when in the original moist condition. In this skarn-like mass the cobalt minerals, mainly cobaltite, occur very irregularly distributed, ordinarily in crystal aggregates, but at times in good crystals, with copper pyrite, as well as a little zinc-blende, hematite and magnetite. The cobalt ore is sometimes gathered in nest-like or lenticular bodies. Stringer-like segregations of ore were also observed in the midst of the gangue. Certain parts of the deposit consist of a granular-crystalline aggregate of barite carrying disseminated grains of copper pyrite and blende, the latter bordered and netted by films of galena.

A second cobalt deposit, probably similar, is known between Dashkessan and Bayan.

The mining operations at the cobalt ore deposit just described have been conducted since 1866 by a German firm (Siemens), and seem to have attained their greatest prosperity toward the end of the sixties. Thus in 1869, 187.5 tons of cobalt were obtained and shipped to the Saxon Bluing Works[1].

Cobalt is produced by only one mine in the United States, Mine La Motte, near St. Louis, Mo., where the cobalt is recovered as a by-product of the lead ores. The cobalt occurs in copper and iron pyrite intermixed with galena in irregular orebodies in a bed of limestone, and is found along a northeast fault. (See Mississippi Valley Lead Deposits.)

[1] 'Annales des Mines,' 1892, p. 503.

VI. Bedded Gold Deposits in the Crystalline Schists.

1. *The Gold Deposits of the Appalachian States*[1].

The Appalachian gold deposits are found in the Piedmont plateau, an upland zone between the Atlantic coastal plain and the mountain ranges of the Alleghanies. This region begins in Nova Scotia, where gold was discovered in 1861 at Halifax, and thence continues in a southwesterly direction as far as Alabama. In the Southern States the occurrence of gold was known to the early Spanish explorers. The deposits occur in crystalline schists, such as micaceous gneisses, hornblende gneisses, mica schists, hornblende schists, quartzitic, chloritic and sericitic schists, supposedly of Archean, Algonkian or Paleozoic age. In the gold areas these rocks are usually completely decomposed to a depth of 15 to 30 m. (50 to 60 ft.) into clayey masses, called by G. F. Becker saprolite.

The great majority of the deposits consist of zones containing numerous, often closely crowded quartz stringers and lenses, mostly perfectly parallel to the schistosity, but occasionally crossing it. These quartz stringers carry auriferous pyrite, and to a less extent auriferous chalcopyrite and arsenopyrite, as well as galena, zinc-blende, and in rare cases, as at Kings Mountain mine, N. C., tellurides. As fragments of the surrounding crystalline schist are not infrequently found included in the quartz, the epigenetic nature of these gold quartz stringers is beyond doubt. This conclusion is confirmed by the occurrence, rare though it be, of true fissure veins (see pages 297 and 299) of the same mineral composition. Besides the workable quartz lenses, there are also fahlband-like zones of impregnated schists, containing the ore minerals mentioned above in fine grains disseminated through the rock. These impregnated rocks are silicified.

The immigration of the auriferous solutions probably took place before Jura-Trias time, since the conglomerates belonging to that epoch also contain gold. This inference of course supposes that the gold content of these Jura-Trias conglomerates is alluvial and not introduced into the conglomerates at some later period.

Among the numerous examples, special interest attaches to the deposits of this kind near Dahlonega in Georgia, which carry tetradymite.

[1] Important publications: H. Credner: 'Beschreibung von Mineralvorkommen in Nordamerika.' *Berg. u. Hütten. Zeit.*, 1866, pp. 55, 144. Same author: 'Geogn. Skizzen aus Virginia, Nordamerika,' *Zeit.* d. D. G. G., 1866, p. 77. W. B. Phillips: 'The Lower Gold Belt of Alabama,' *Bull.* 3, Geol. Surv. of Alabama, 1892. G. F. Becker: 'Reconnaissance of the Gold-Fields of the Southern Appalachians,' *Ann. Rep.* U. S. Geol. Surv., 1894–95, Vol. XVI, p. 289. H. B. Nitze: 'The Gold-Ores of North Carolina,' *Bull.* 3, Geol. Surv. of N. Carolina, 1895. Also 'Gold Mining in the Southern Appalachian States,' *Trans.* Am. Inst. Min. Eng., 1895.

According to H. Credner, a zone of chloritic schist only 8 cm. (0.26 ft.) thick, bounded neither by surfaces of stratification nor by fissures, but quite distinct, contains many stringers of quartz, 1.5-3 cm. thick, as well as nut-shaped masses of this mineral. This quartz carries besides garnet, flakes of silvery white mica, pyrite and brown hematite, many small scattered scaly patches of light lead-gray tetradymite. Small fissure-shaped druse cavities also extend through the surrounding chloritic schist and hold native gold in botryoidal masses, penetrated by clear crystals of quartz. Aggregates of crystallized gold often hang to the schist by a mere thread. Gold is also found in the hornblende gneiss of Dahlonega, which is there found intercalated between itacalumite-like quartzite slates. In this case the gold exists in moss-like wire or scaly particles penetrating the quartz stringers and associated with bismuth telluride (tetradymite). Eckel has recently (1903) examined the gold mines of the last named locality, and finds that the veins all occur at contacts between the soft mica schists and igneous rocks, either altered schistose diorites (amphibolites) or massive granite[1].

The gold quartz beds of Faribault in Nova Scotia are another remarkable example. They are, with few exceptions, associated with anticlinical folds of the schist and quartzite, and occur at points, which in consequence of a secondary anticlinical folding, show a dome-like uparching, being thus analogous to the saddle lodes of Bendigo. Eleven such anticlinals, approximately parallel, are known east of Halifax[2]. Of the 21 arches of strata on the anticlines, 14 contain caps of gold quartz now worked, while 6 others have at least been demonstrated. The layers generally parted or slipped along the contact plane between quartzite and slate, the movement being shown by slickensides. The cavities thus formed, very gradually during flexure, were as gradually filled with the auriferous quartz, as proved by the crusted structure of the orebodies. The thickness of the anticlinal lodes thus far worked varies between 0.4 m. and 0.7 m. (1.3 ft. and 2.3 ft.). In the Golden Hill dome, some 55 different orebodies have been traced on the north side of such an anticline. For that matter, true fissure veins of identical composition are known in the region.

2. *The Homestake, South Dakota, Gold Deposits.*

Gold deposits of the Appalachian type also occur near Lead, in the Black Hills of South Dakota. The Homestake zone of impregnated schists takes its name from that of the "biggest gold mine of the world." The

[1] *Bull.* 213, U. S. Geol. Surv., 1903, p. 57.

[2] E. R. Faribault: 'The Gold Measures of Nova Scotia and Deep Mining.' Paper read before the Can. Min. Inst., March, 1899.

Homestake orebody is not a fissure vein, but a broad impregnated zone in the schists, with a course of north 34° west, cutting at a slight angle across the foliation of the schists. The ore occurs in lenses dipping east and pitching south. The orebodies near the surface appear to follow intrusive dikes and masses of rhyolite porphyry, but in depth they diverge from them and in part are associated with a greenish-colored phonolite.

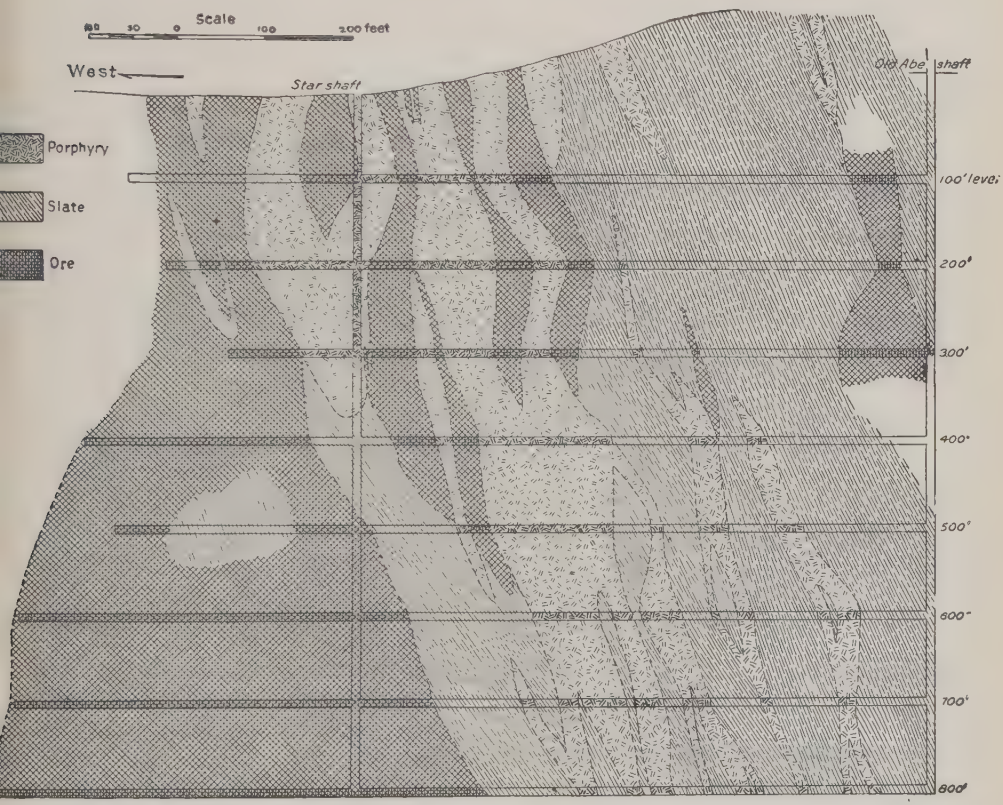


Fig. 203*a*.—Cross-section of the Homestake orebody, near Lead, South Dakota. (Emmons.)

The usual ore is made up of quartz and pyrite, with or without accessory dolomite, calcite, and arsenopyrite. Sometimes garnet and tremolite appear, but the values are independent of the accessory minerals. According to Irving[1] the ores occupy a zone of schists differing from the normal schists in a greater amount of distortion and the presence of secondary minerals. There have been several different periods of mineralization.

[1] *Bull.* 225, U. S. Geol. Survey, 1904, p. 123. 'Economic Geology of the Northern Black Hill,' Prof. paper No. 35, U. S. Geol. Survey, 1904.

The main orebody is 500 feet wide and averages $3.50 per ton. The ore after stamping is run over plates and then cyanided. This great property was acquired by the Homestake Company in 1877, and equipped with an 80-stamp mill the following year. At the present time the corporation owns 2,600 acres of mineral land, developed to a depth of 1,250 feet, and treats 4,000 tons a day in mills aggregating 1,000 stamps. The total production up to January 1, 1904, is $75,000,000, of which $20,000,000 was distributed as dividends.

3. *Other Examples of This Type.*

In South America the type occurs in Brazil, especially in the region west of the Sierra Mantiqueira[1]. In the region of Ouro Preto certain layers of sandy specular hematite only a few centimeters thick, found within the itabirites, are sometimes rich in gold, occurring in nuggets, flakes, and as wire gold. A famous example occurs at the Gongo Socco mine, which from 1826 to 1856 produced 12,887 kilograms of gold out of such zones as Jacutinga[2] (specular hematite sandstones)[3].

In Africa this class is, according to Schmeisser[4], found in the gold deposits of the Sutherland mine west of Leydsdorp, and according to Molengraaff[5] another example occurs in the crystalline schists of Barberton, both in the Transvaal. Most of the gold deposits of the so-called Gold Coast of West Africa, north and south of the Kong mountains, belong to this class. Mining was formerly carried on there in the following districts: Denkira, including Wassau, Encasse, Juffer and Commendah, Acanny, Akim, Ashanti, Adansi and Aowin. The gold-bearing conglomerates of Tarkwa in Wassau will be discussed further on. The production, formerly considerable, has now declined to an annual average of 102,000 pounds sterling[6].

This type of deposit occurs in Europe also, but apparently has not been scientifically studied with the same degree of accuracy as the American Alleghany occurrences. They occur, according to J. G. Klemm, in Spain,

[1] A. Pissis: 'Vorkommen und Gewinnung des Goldes in Brasilien,' *Berg u. Hütten. Zeit.*, 1842, p. 752.

[2] H. K. Scott: 'The Gold-Field of the State of Minas Geraes,' *Trans.* Am. Inst. Min. Eng., Feb. and May, 1902.

[3] This is regarded by Harrison as concretionary ironstone, resulting from surface decomposition of auriferous basic rocks, from which the iron is dissolved to form a surface mantle, cementing residual sand. Brit. Guiana Govt. *Report*, 1900. 'Geol. Essequibo,' etc. (W. H. W.)

[4] Schmeisser: 'Ueber Vorkommen und Gewinnung nutzbarer Mineralien in der Südafrikanischen Republik,' 1894, p. 33.

[5] G. A. F. Molengraaff: 'Géol. de la Rep. Sud-Africaine,' p. 17.

[6] *Zeit. f. Prak. Geol.*, 1899, p. 374.

as the gold-bearing quartzites of the Sierra Guadarrama north of Madrid[1]. According to Th. Breidenbach[2], gold also occurs as minute specks impregnating schist, in the once famous Roman gold mining area of the Somedo mountains in northwestern Spain. The Romans worked only the gold-bearing schists, but did not touch the quartz veins of the region because their gold content is very low.

4. *The Gold Deposits of Zell in the Ziller Valley, Austria.*

According to A. R. Schmidt[3], the mica schists, phyllite[4] schists and talcose schists of the Ziller Valley, at the Tannenberg, Heinzenberg, and at Rohr near Zell, as well as at the Leimacher Berge, near Hippach, and thence as far as Thurnberg and Kaltenbach, contain a number of gold-bearing quartz segregations. They lie parallel to the foliation and are ordinarily accompanied by blackish-gray clay slate, finely impregnated with arsenopyrite and pyrite. These gold-bearing schist bands contain milky white or bluish quartz quite unlike the glassy quartz of barren stringers which also occur there. The individual beds can be traced only a short distance, though together they form a long and well defined zone. Most of the beds are not workable. The Vincenzi mine, on the Heinzenberg near Zell, is the only property showing extensive development. It is to be noted that, besides the nine beds which were formerly worked there, barren quartz veins are also known in the gray clay slate. The beds are parallel in strike and dip (65° to 75° south), and are from a few centimeters to 12 m. (39 ft.) thick, and lie near one another. The most important bed is the Friedrichslager, in which an orebody 120 to 140 m. wide, and extending diagonally downward, was found to be workable. This distribution of the ore in the form of shoots (Adelsvorschübe) is a proof in favor of the epigenetic origin of these deposits. For that matter these deposits do not by any means consist entirely of quartz, but mainly of schist with quartz stringers.

The values occur mostly as minute particles of native gold, finely disseminated or, rarely, in visible granules and flakes. The ordinary gold contents were, per ton:

For sifted quartz	35–122	grams.
For unsifted quartz and schist	5.2	"
For auriferous schist	1.8	"

[1] J. G. Klemm: 'Das Vorkommen des Goldes im mittleren Spanien,' *Berg. u. Hütten Zeit.* 1867, p. 125.

[2] Th. Breidenbach: 'Das goldvorkommen im nördlichen Spanien,' *Zeit. f. Prak. Geol.*, 1893, p. 20.

[3] A. R. Schmidt: 'Geognostich-bergmännische Skizzen über die Erzlagerstätten Tyrols.' *Berg. u. Hütten. Zeit.*, 1868, Vol. XXVII, pp. 9-11, 53, 54.

[4] Phyllite is a hardened metamorphosed slate.

One ton of schist, however, corresponded as a rule only to 3.8 kilog. of quartz.

The Vincenzi mine was opened in 1628. In 1858 it was sold by the crown to a company. Having been temporarily abandoned, it is to be presently reopened.

5. *Gold-Bearing Quartz-Diorite Gneiss of Mashonaland.*

At the Ayrshire mine in the Lomagunda district, Mashonaland, a dike-like mass of gold-bearing diorite gneiss occurs intercalated between hornblende and chloritic schists, about 100 ft. from a granite mass. It has a steep northerly dip, is exposed for a length of 210 meters (689 ft.) and

Fig. 204.—Hornblende gneiss of Lomagunda. (Enlarged 150 times in polarized light.)
o, orthoclase, with inclusions of gold; pl, plagioclase; q, quartz; h, hornblende; e, epidote (all four with inclusions of gold); pn, plagioclase with hornblende microlites; il, ilmenite with titanite borders; t, titanite; b, biotite; m, pyrrhotite.

is proven for 600 ft. in depth. The vein has an average thickness of 20 ft., though but 10 ft. of this is pay ore. The average gold contact is 23 grams ($15) per ton, though this rises at times to 30 grams, and in one instance to 45 oz. ($930) per ton. The rock is a fresh fine-grained quartz diorite gneiss, of gray-green color, and faint gneissoid structure, composed of pale-green hornblende, oligoclase-albite feldspar, some quartz and accessory biotite, magnetite and epidote. The gold is intercrystallized with the other constituents, and of contemporaneous formation, but is most abundant in hornblende bands. (Spurr.)

When exposed to examination under a suitable microscope the free gold is observable in the form of rounded grains, elongated crystalline particles or minute many-sided crystals. It forms inclusions in quartz, plagioclase, orthoclase and in the green hornblende, as well as in the epidote. A light-colored pyrite, also present, apparently a non-magnetic pyrrhotite, though not the real carrier of the gold, is occasionally intergrown along the margin with gold granules. The diagrammatic thin section (combined from different parts of the slide and greatly enlarged) shows the mode of occurrence of the precious metal. Its present distribution and development was evidently simultaneous with the metamorphism of the rock. Of course this transformation effaced all evidence as to the origin of the gold[1].

6. *The Auriferous Gneisses of Madagascar.*

From specimens furnished by Superbie, A. Lacroix[2] showed that on the Mandraty river in Madagascar biotite gneisses occur, in whose constituents (quartz, orthoclase, oligoclase and biotite) tiny crystals of gold are enclosed, while besides these, independent grains and crystals of gold are abundant in the composition of the rock, which, by the way, is entirely free from pyrite. The gold is contained in the same way in the magnetite-bearing quartzites of the same region. The author just named also alludes to the occurrence of gold as a normal constituent of a gneiss in the Campanha district in Brazil, reported by O. Derby[3].

(b) Epigenetic Ore Deposits Formed Essentially by Impregnation Within Non-Crystalline Strata.

(a) pyrite deposits.

1. *The Rammelsberg Pyrite Deposit Near Goslar.*

The Rammelsberg is a mountain on the northern border of the Harz, two miles south of the old city of Goslar. It is composed of beds belonging to the Devonian, forming an overturned fold, as shown in the section, Fig. 205, after F. Klockman, from whom this description is mainly derived.

[1] J. E. Spurr: 'Native Gold original in Metamorphic Gneisses,' *The Engineering and Mining Journal*, February, 1904, Vol. LXXVII, p. 198. Also, same journal, October 3, 1903, p. 500. E. D. Berrington: 'Gold in Diorite,' same journal, July 11, 1903, p. 44.

[2] A. Lacroix: 'Sur l'origine de l'or de Madagascar,' *Comptes rendues* de l'Acad. d. Sc., Paris, Jan. 21, 1901, Vol. CXXXII, pp. 180-182.

[3] Described in this work under heading 'Pyritic Deposits in Crystalline Schists.'

According to him the deposit is intercalated in clay slates of the Middle Devonian (Goslar slates) forming the under side of the Rammelsberg anticline. The slates are overlain by the Calceola shale and, higher up, by the lower Devonian Spirifer sandstone, forming the core of the fold.

The bed is composed of lenticular bodies of compact, distinctly banded ore, whose layers are conformable with the bedding of the Goslar slate, so that all the numerous folds and wrinkles of the shale have also found expression in the ore deposit. Moreover, a great spur, or branch stringer of the orebody that runs off into the overlying strata, is generally accepted as due to a buckling or closed fold of the deposit. The compression and wrinkling are especially pronounced in the footwall of the orebody, where there are also numerous fractures extending into the ore. This foot-wall

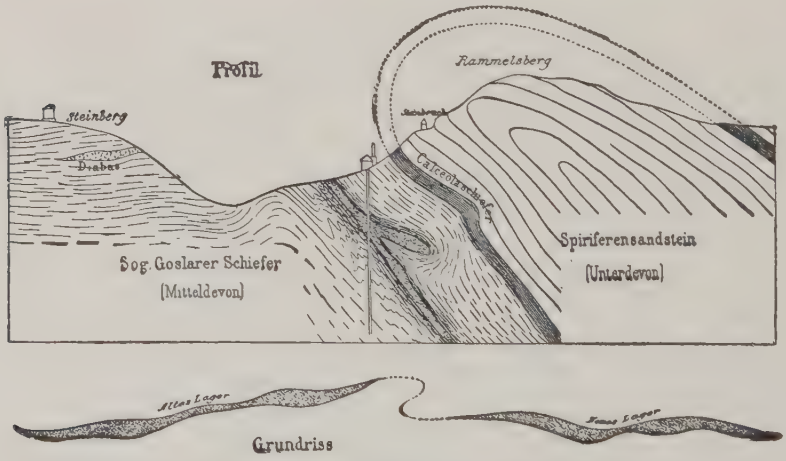


Fig. 205.—Sketch of the Rammelsberg ore deposit. (Klockmann.)
Grundriss = ground plan.

zone of maximum dynamic effect is ordinarily called Wimmer's leading stratum and is usually interpreted as an overthrust fault plane resembling the Ruscheln[1] (fault lodes) in character. Besides a forking in dip of the main orebody, forming the main deposit and its great branch, an S-shaped bend also exists along the strike as a result of the folding. (Fig. 205.) This flexure shifts the deposit to the foot-wall side. When in 1859 the orebody was recovered by a drift beyond this displacement the shifted position was called the 'new deposit.'

The deposit is normally 15 to 20 m. (49 to 65 ft.) thick, but at the intersection of the stringer it is 30 m. The known length of the old deposit is 1,200 m. (3,936 ft.) The dip is 45° southeast.

[1] G. Kohler: *Essener Glückauf*, 1894, p. 1615.

The deposit consists of distinct layers of different mineralogic composition, arranged in definite order from the hanging to the footwall, that is to say, from the older to the younger slate strata.

1. Schist-carrying pyrites, the so-called *Kupferkniest* (gangue crossed by small copper veins).

2. Dense ore, composed of an intimate mixture of copper pyrite and iron pyrite, with some arsenopyrite.

3. Mixed ores, that is to say, finely banded layers of pyrite and galena.

4. Fine-grained mixture of galena, zinc-blende, pyrite and barite, the so-called lead ores, which are:

(a) Brown ores when blende predominates.

(b) Gray ores when barite predominates.

The name banded ores is given to finely laminated, often strongly folded and wrinkled material, in which layers of slate alternate with fine layers of ore. Such banded ores often form a transition of the main ore deposit to the schist, especially on the northeast, but also quite similarly on the southeast.

The ores of the Rammelsberg deposit proper are dense and compact. In transverse vein fissures, on the other hand, the ore minerals are crystallized, including copper pyrite, galena, gray copper, zinc-blende, barite, calcite, siderite, quartz and calamine in pseudomorphs after calcspar.

In the "Alte Mann" (old man), meaning the dumps formed of pieces cemented by new materials, the secondary minerals formed in historic times include copper, iron and zinc sulphates, botryogen (a hydrated sulphate of iron and magnesia), copiapite (basic sulphate of Fe), glockerite, gypsum and epsomite.

Many authors[1] still adhere to the opinion first advanced by K. von Böhmer, that the Rammelsberg deposit is of sedimentary origin. As late as 1895, F. Klockmann tried to sustain the view that the ore had been deposited in a flat syncline of the Devonian sea bottom, which had already been filled with mud. According to him, the compact ore mass is traversed by fine layers of slate, as by "annual rings," and the reason why the lead ores occupy a larger area is that, beyond the youngest sheet, they had the

[1] Important papers: G. S. O. Lasius: 'Beobachtungen über das Harzgebirge,' 1789-1790, p. 373. C. F. Freiesleben: 'Bemerkungen über den Harz,' 1795, Vol. II, p. 75. H. Credner: 'Geogn. Verh. Thüringens und des Harzes,' 1843, p. 121. B. v. Cotta: 'Erzlagerstätten,' 1861, II, p. 103. A. W. Stelzner: 'Die Erzlagerstätte vom Rammelsberg bei Goslar,' *Zeit.* d. D. G. G., 1880, p. 809 *et seq.* G. Köhler: 'Die Störungen im Rammelsberger Erzlager bei Goslar,' *Zeit.* f. B. H. u. S. im pr. St., 1882. p. 31. A. v. Groddeck: 'Geognosie des Harzes,' 1883, p. 118. J. H. L. Vogt: 'Ueber die Genesis der Kieslagerstätten vom Typus Röros-Rammelsberg.' *Zeit. f. Prak. Geol.*, 1894, p. 173. F. Klockmann: 'Im Berg- und Hüttenwesen des Oberharzes,' 1895, p. 37 *et seq.* Söhle: 'Beitr. z. K. d. Erzlagerstätte des Rammelsberges,' *Oesterr. Z.* f. B. u. H., 1899.

widest area of the flat syncline for their distribution. The origin of the solutions he leaves undetermined, but thinks that they may possibly have been connected with the diabases.

Against this, others, and J. H. L. Vogt in particular, have advanced modern arguments on behalf of the old theory, dating back to C. F. Freiesleben, *i. e.*, that the ores penetrated into the schist rocks after their formation, Freiesleben regarding the deposit as a lode. Vogt's main arguments to support this view depend on the fact that the deposit lies alongside of a great dislocation fissure, and that there is a lack of littoral material in the country rock, although a sedimentary formation of the character postulated is only possible in a very shallow sea and in shallow bays. His reference to a possible connection of the ore deposit with the injection of Ocker granite 3 km. distant, or even with the Radau gabbro, 8.5 km. away, is regarded as of very doubtful significance.

The subsequent introduction of the ore seems to us the more likely theory. The deposition of the metallic minerals may have been by a replacement of layers of the slate, either a calcareous bed or one made up of basic silicates. A microscopic examination of specimens of the ore, which, it is true, needs to be extended, disclosed nothing at variance with that view. The real receptacle of the ores is an impure limestone, having layers of rather coarse crystalline, dark-tinted impure limestone. The ores have largely penetrated between the aggregates of carbonate crystals as an exceedingly fine veining. In the slaty layers, richer in quartz and sericite, the ore appears in thin sections to resemble the large scale sections showing parallel stripes, which may represent former layers of calcspar.

The beginning of the mining industry at Rammelsberg is ordinarily referred to the year 968. At that time, during the reign of Otho the Great, the town of Goslar already existed, having been founded, it is said, about 930. The production of the mine in 1898 was 34,804 tons of lead ore and 26,313 tons of copper ore.

2. *The Pyrite and Barite Deposit of Meggen on the River Lenne.*

This is the most important pyrite deposit of Germany, and it is of special interest for the reason that in this case one part consists of iron pyrite and another part entirely of barite, these minerals replacing each other along the same bed.[1]

The ores occur in a bed 10 ft. thick, that is, conformably inter-

[1] M. Braubach: 'Der Schwefelkiesbergbau bei Meggen an der Lenne,' *Z.* f. d. B. H. u. S. im preuss. St., 1888, Vol. XXXVI, pp. 215-222. R. Hundt: 'Das Schwefelkies- und Schwerspathvorkommen bei Meggen a. d. Lenne,' *Zeit. f. Prak. Geol.*, pp. 156-161; with list of older works. Denckmann: Kurze Mitth. *Zeit.* d. D. G. G., 1900, p. 112.

bedded in the Middle Devonian strata, forming the Attendorn-Elsper synclinal basin, here forming a pronounced syncline with a steep southeast and a less inclined northwest flank. The latter flank is accompanied at the village of Meggen by two other troughs, whose connection with each other, like that with the main syncline, has been destroyed by erosion. The chief syncline has been traced along the strike for a distance of 5 km. Subordinate folds occur repeatedly in the larger synclinal basin, as well as a series of small transverse displacements (see section, Fig. 206).

Underlying the deposit, which averages 3 m. (10 ft.) and is at most 8 m. (26.2 ft.) thick, are graywacke slates (Lenneschiefer). Overlying it are dense nodular limestones carrying fossils (*Prolecanites*) and inclusions of iron pyrite. These limestones are in part dolomitic, and are overlaid by clay slates with false schistosity.

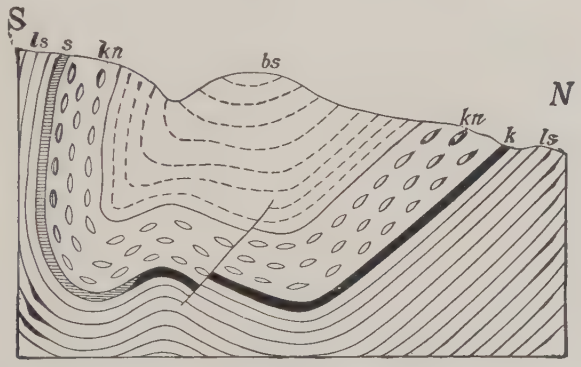


Fig. 206.—Section through the pyrite and barite deposit of Meggen. (Hundt.)
ls, Lenne slate; kn, nodular limestone; bs, Rüdesheim slates; k, iron pyrite; s, barite.

In the middle part of the syncline the deposit consists of pyrite; at the south and east of barite. The line of division between the two is sharp; there is no middle zone with a mixture of the two ingredients or with a thinly stratified alternation of the different ores. The only transition is where the pyrite at first appears as a narrow, hardly perceptible clay coat along the foot-wall, increasing in thickness more and more, until finally it has entirely replaced the barite. While at the outcrop on the Lenne near the village of Meggen only barite is found, in one of the lateral synclines these transitions, with barite at top and iron pyrite at bottom, may be traced to a distance of about 100 m. (328 ft.)

The iron pyrite is distinctly stratified, occurring in fine layers, which often show the same fine wrinkling as the adjoining slates. In some parts it possesses a peculiar structure, resembling oolite. Round granules of ore,

varying in size from that of a poppy seed to that of a grain of millet, lie closely packed together. Some of these grains are hollow, and show ring-shaped figures in thin sections, the center of the grain and the interspaces between them being filled with dark barite. The barite shows, on the contrary, both to the naked eye and in thin sections, a massive structure. Under the microscope, it has an exceedingly fine-grained crystalline structure, with numerous brown flakes of bitumen scattered between the grains. An important structural feature is the presence of forkings of the pyrite layer, like those of the Rammelsberg deposit, but on a smaller scale. Such features are assumed to be due to faulting, by which barren rock is brought against the end of the lode, as shown in Fig. 206.

The iron pyrite composing the deposit is colored blackish by organic ingredients. Layers of dark brown dense zinc-blende occur mingled with it, so that the ores contain on an average 8% of zinc, for which reason the pyrite beds are worked for zinc. On the contrary, the proportion of copper pyrite and galena present is trifling. The finely granular crystalline barite, blackened by organic matter, contains about 2% of strontium sulphate.

Denckmann conjectures that the Meggen deposit is an alteration product of the Stringocephalus limestone, which is greatly thinned at this point.

In 1900 the Sicilia and Siegena mines at Meggen yielded 145,122 tons of pyrite.

3. *Pyrite Beds in the Paleozoic Rocks of the Austrian Alps.*

In the Austrian Alps, several pyrite beds of this kind occur in Paleozoic schists. We will mention only two examples.

At Kallwang, in Upper Styria, according to R. Canaval[1], the Schatzlar graphitic schists (Lower Carboniferous) contain an interbedded mass 0.3 m. to 1.2 m. thick, traceable for 3,500 m. (2.1 miles) along the strike and developed for 300 m. (984 ft.) in dip. The ore consists mainly of pyrite, with associated pyrrhotite, chalcopyrite and some arsenopyrite. The copper pyrite occurs in workable amount in the upper part. In this part it encloses large cubes of pyrite. Copper mining, which is known as early as 1469 at this place, ceased in 1867.

Similar deposits are worked in the Walchern Graben, near Oeblarn, Upper Styria. According to Söhle[2], micaceous clay schists, probably of Silurian age, contain two beds of pyrite-carrying copper pyrite, pyrrhotite and some galena, with some quartzose gangue. The mine was reopened in 1897 and is still worked.

[1] R. Canaval: 'Das Kiesvorkommen von Kallwang,' etc. *Mitth.* d. naturw. Vereins für Steiermark, 1894.

[2] Söhle: 'Ueber den Kiesbergbau bei Oeblarn.'

On the other hand, the Styrian silver-lead deposits found in the Devonian schists of the region of D.-Feistritz-Peggau, Frohnleiten, Ubelbach, and Thalgraben, near Gratz, are of different character. They consist essentially of silver-bearing galena and zinc-blende, with quartz, calcite, witherite and barite, and though formerly described as beds, they must, as a result of the detailed studies made by W. Setz[1], be accepted as bedded veins of the carbon-spathic-lead group.

The pyrite deposit of Agordo, in the Venetian Alps, was formerly a great producer, but is now closed down[2].

From former reports it is known that this famous orebody, whose form has been compared by E. von Cotta to that of a flattened sausage, 4 m. to 80 m. (13 ft. to 262 ft.) thick, extends to a depth of 460 m. (1,508 ft.) and is surrounded on all sides by sericitic schists of undetermined age. The orebody consists of compact iron pyrite, containing on an average hardly 2% copper, and carries also some argentiferous blende, galena, arsenopyrite, as well as quartz and calcspar. Rich copper ores also occur, with 2 to 8% and rarely 8 to 30% copper. As late as 1880 Agordo produced 14,872 tons of ore. A similar deposit has lately been developed at Vallimperina, in the same district[3].

4. *The Pyrite Deposits of Huelva, in Southern Spain and Portugal*[4].

The Sierra de Aracena forms a western continuation of the Sierra Morena, and like it consists of crystalline schists. This range is succeeded to the south by a northwest-southeast zone of metamorphosed Paleozoic rocks, part of the beds being known to belong to the Silurian and Culm, while the age of other parts has not yet been positively determined. The strata are nearly vertical, and contain intercalated sheets or dikes of porphyry varying from quartz porphyries to diabase porphyrites. They are not confined to any definite horizon, and hence it cannot be maintained, as Klockmann tried to do, that they are effusive flows. The presence of ac-

[1] 'Die Erzlagerst. d. Geg. von D.-Feistritz-Peggau,' etc., *Zeit. f. Prak. Geol.*, 1902, pp. 357-378, 393-414.

[2] B. v. Cotta: 'Agordo,' *Berg u. Hütten Zeit.*, 1862, pp. 425-427. B. Walter: 'Beitrag zur Kenntniss der Erzlagerstätte von Agordo,' *Oesterr. Z.* f. B. u. H., 1863, pp. 114-119. A. St. Schmidt: 'Geogn.-bergm. Skizze über den Kiesstock zu Agordo,' *Berg u. Hütten. Zeit.*, 1867, pp. 240-241.

[3] 'Revista del Servizio Minerario nel, 1894,' p. 293. (Cited from Phillips-Louis.)

[4] Literature: Ferd. Römer: *Zeit.* d. D. G. G., 1873 and 1896. Gonzalo y Tarin: 'Descripcion física, geológica y minera de la Provincia de Huelva,' Madrid, 1886-88, Vols. I-III. L. de Launay: 'Mémoire sur l'industrie du cuivre dans la région d'Huelva,' *Ann. d. Mines*, 1889. With bibliography. F. Klockmann: 'Ueber die lagerartige Natur der Kiesvorkommen des südlichen Spaniens und Portugals,' *Sitzber.* d. k. preuss. Ak. d. W., Berlin, 1894. J. H. L. Vogt: 'Das Huelva-Kiesfeld in Südspanien und dem angrenzenden Theile von Portugal,' *Zeit. f. Prak. Geol.*, 1899. pp. 241-245. Gregory, *The Engineering and Mining Journal*, Feb., 1905.

companying tuffs, described by him, is as yet unproven. Towards the south the slates pass beneath a cover of Tertiary formations characteristic of the coastal area, while towards the east the slate belt terminates in the sharp fault scarp of the Guadalquivir valley. The orebodies occur intercalated in the slates, and are mostly pyrite lenses, of which more than fifty are enumerated, mostly at or near the contact with the dikes of porphyry, with the presence of which they are evidently closely connected. They are found in a zone about 200 km. (120 miles) long, but are especially well developed in a strip about 80 km. (48 miles) long and 20 km. (12 miles) wide, running east and west, in the Spanish province of Huelva and the Portuguese province of Alentejo, between Rio Tinto and San Domingo. The San Domingo mine, as well as La Zarza and Tharsis mines, which lie nearer the center of this zone, are the principal producers of the district, their product

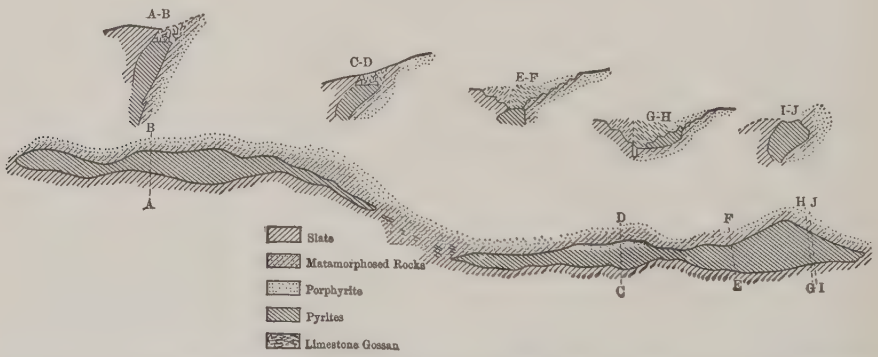


Fig. 207.—Plain and cross-sections of Rio Tinto orebodies, Huelva, Spain. (Gonzales.)

being shipped through the port of Huelva, in part also down the navigable Guadiano river and by way of Villareal.

The deposits are lenticular in shape and very thick, the Dionisio bed being 150 m. (492 ft.) across, but they often wedge out within a distance of a few hundred meters, both in strike and in depth. The accompanying cross-section, Fig. 207, after Gonzales, gives an idea of the relation of the ore lenses to the schist and porphyry. The horizontal cross-section of the compact pyrite mass of the largest lens, Dionisio, is about 60,000 to 70,000 square meters, and the entire area of pyrite deposits of the Huelva district is estimated by Vogt at about half a million sq. m., while the total pyrite mass which nature had concentrated here, before it was depleted through erosion and mining, is estimated by him at 1,000 million tons at least. The pyrite is mostly compact, finely crystalline and exhibits frequently a banding or stratification parallel to that of the slate.

The Iberian pyrite consists predominantly of pyrite with but little quartz and with a little copper pyrite. The average copper content varied during the last ten to twenty years between 2.6 and 3.2%. The amount of arsenic averages 0.2 to 0.6%. At one mine, Aguas Tenidas (Confesionario) the pyrite is free from copper and arsenic. It is notable that the amount of copper generally decreases in depth. At the Domingo deposit, for example, the copper content close below the gossan was about 4 to 5%; at a depth of 60 to 70 meters it had decreased to about 2%, at 100 m. to about 1.5%, at 130 to 140 m. to about 1%. This no doubt is due, for the most part, to the fact that the original copper content of the gossan zone, usually 10 m., at times 50 m. thick, was dissolved and then redeposited in fissures directly below the gossan, in the form of copper glance, bornite and chalcopyrite. It was this network of narrow secondary copper ore lodes that the old Romans followed with their mining operations. Directly below the gossan, in a mine, North bed No. 2, at Rio Tinto, is an earthy zone, 1 to 2 decimeters thick, with 15 to 30 grams gold and 1¼ kg. silver per ton, a concentration of the minute amount of the precious metals in the pyrite leached out in gossan formation and redeposited.

Old implements in the mines prove that the mining operations in the Huelva district were carried on by the Phœnicians, who came to Spain in the 11th century B. C. The Romans have left traces of very extensive work. In the 8th century all the work was stopped, and even after the expulsion of the Moors it remained insignificant, until energetically resumed about 1850. In 1898 and in 1902, the mines produced the following amounts of copper, in metric tons:

	1898.	1902.
Rio Tinto	34,244	35,041
Tharsis	12,192	6,817
San Domingo	3,658	3,386
Sevilla	813	462
Other mines	3,170	5,071
Total	54,077	50,767

The ore averaged 2.517% in 1902.

These totals, in view of the low copper percentage, imply an enormous production of pyrite, which for the total Huelva district amounted in 1893-1896 to 2,500,000 tons in round numbers. In the eighties, the Huelva district supplied between 1/5 and 1/4 of the copper production of the whole world, in 1897 only 1/7, having been meantime distanced by Montana and Michigan. According to Vogt, the Iberian copper production has now reached its climax, while the production of pyrite is still increasing.

5. *The Mount Lyell Gold-Silver-Copper Deposit.*

Near the west coast of Tasmania, on the north slope of Mount Owen, there is a zone of soft mica schists, called pyrophyllite schists by some writers, which contains bands of conglomerates and quartzite, as well as numerous stringers of slightly auriferous pyrite. The Mount Lyell pyrite bodies lie in these schists along the conglomerate contact. The orebody is 250 ft. thick and 620 ft. long on the surface and down to the 4th level, but grows smaller, and 300 ft. below is about 170 by 360 ft. The limonite gossan was from 1880 to 1890 worked solely for free gold ($20 to $25 gold and 20 to 25 oz. silver per ton), and the real importance of the deposit was only recognized when, some years later, pyrite was encountered and opened up. The primary ore consists of granular crystalline pyrite with interspersed copper pyrite and has an average content of 0.66 to 4.5% copper, as well as some 62 grams (2 oz.) silver and 4.5 grams gold ($3) per ton. An analysis of this "poor ore" communicated to A. W. Stelzner by O. Schlapp in 1893 showed:

Fe	41.06
Cu	4.81
Pb	trace.
As	trace.
Ag	0.01
Au	0.0005
S	50.41
$BaSO_4$	3.81
SiO_2	0.25
	100.3505

The rich ores occur in a quartzose mass along one wall. This ore contains crystalline pyrite, nests and stringers of coarse-grained copper pyrite, bornite, stromeyerite, sulphides of silver and copper, gray copper and some galena. Some samples consisted in part of fine-grained, more rarely scaly barite. Others carried nests of barite and quartz, as well as cavities filled with an ocher containing 3.47% Ag (Kolbeck) and traces of gold. Domeykite was present as a rarity.

These rich silver-copper ores are probably secondary concentrations immediately below the gossan proper. The principal mine, the Mount Lyell, yielded 3,608 tons copper, 341,346 oz. silver and 11,681 oz. gold in 1902.

6. *The Copper Deposits of Iron Mountain, California.*

The copper deposit of Iron Mountain, in Shasta County, California. is in many respects similar to the preceding example. It is one of the many

copper deposits occurring in a crescentic area on both sides of Sacramento river (Shasta County copper belt)[1].

The copper belt of Shasta County, California, contains two mines of importance, viz.: Iron Mountain and Bully Hill. The Iron Mountain mine lies west of the Sacramento Valley, near Redding. The orebody is covered by a mass of limonite 100 feet thick, which was for some years worked for its gold and silver contents. The deposits consist of two elongated flattened lenses, the first on Iron Mountain 800 feet long, and 100 to 400 feet wide, worked for 600 feet in depth. The Hornet orebody is narrow, but longer. These bodies occur in a northeast-southwest shear zone. The dip is vertical or steeply northwest, the orebodies pitch northeast. The ore consists of fine-grained pyrite, with chalcopyrite intimately mixed with it. Zinc-blende occurs in streaks, and often gives the ore a schistose look, such ores occurring adjacent to the schistose metarhyolite. The walls of the orebody show slickensides with sericite selvages in some places. Small transverse faults traverse the ore. According to some observers, the two orebodies are faulted parts of one mass in an altered slaty rhyolite (metarhyolite), a rock remarkable for its high soda and low potash content.

The Bully Hill district is 25 miles northeast of Redding. The orebodies occur in three shear zones in igneous rocks. The common country rock is a metarhyolite (*i. e.,* metamorphosed rhyolite), rich in porphyritic quartz. At the Bully Hill mine, the rock most intimately associated with the orebody is a metabasalt rich in soda, forming a dike cutting the other igneous rocks and Triassic slates. The shear zones are limited, none being traceable over a mile. They vary from a few inches to 20 ft. thick, run a little east of north, and dip at a very high angle to the west. There are three parallel zones, a few hundred feet apart at Bully Hill, two of them mineralized. The west lode is in the metarhyolite forming Bully Hill. The other is in the metabasalt, near the outcrop, but follows the dike contact for 500 ft. in depth. The orebodies are lenticular and sheet-like masses, varying from the size of a nut to lenses hundreds of feet long and nearly 20 feet thick. These are irregularly distributed through the crushed and more or less impregnated mineralized rock of the shear zone. The longer axis usually pitches north. The gossan varies in thickness and extends downward along fissures. It contains gold and silver and copper oxide and carbonates. The primary ore consists of pyrite, with some chalcopyrite and sphalerite in a gangue of barite. The barite is rarely abundant and often so finely disseminated as to be invisible.

Secondary enrichment of chalcocite occurs beneath the gossan and in

[1] The description of the locality is re-written by W. H. W. from recent publications by Diller and others. 'Copper Deposits of Redding Quadrangle, Cal.,' *Bull.* 213, U. S. Geol. Survey, 1903, p. 129. Also *Bull.* 225, 1904, p. 169.

fissures and nests in the primary ore beneath it. Bornite and chalcopyrite also appear as secondary, as well as primary ores.

7. *Mesozoic and Cenozoic Pyrite Beds.*

In Southern France, west of the Rhone, and northeast of Alais (Card), there is a bedded pyrite deposit near St. Julien de Valgalgues. It is 1 to 12 meters thick, and lies between the Lias and Doggen limestone. The presence of pyritized fossils in the bed is correctly interpreted as proving the origin of the deposit by mineral springs.

Still younger deposits of iron pyrite occur in the Upper Cretaceous of Wollin Island. The beds of pyrite concretions in the Lignite formation of the Tertiary may also be mentioned here.

(β) PERMIAN AND YOUNGER BEDDED DEPOSITS OF COPPER.

The Copper Shale of the Zechstein Formation.[1]

The copper shale (kupferschiefer) at the base of the Zechstein formation of Germany is one of the formations of greatest geologic interest and economic importance known. First of all it attracts attention by its wide distribution, which is remarkable even for a stratified ore deposit, extending as it does some 200 kilometers (120 miles) from east to west and some 100 to 150 km. (60 to 90 miles) from north to south, through the whole of central Germany, from the Saale to the eastern edge of the Rhenish schist area. The outcrops of this copper shale bed extend all around the southern Harz, and enclose most of the Thüringerwald. Similar formations, perhaps not of this identical geological horizon, appear at Riechelsdorf, between the Werra and Fulda. Other beds emerge from beneath the recent volcanic area of the Kassel region at Frankenberg and Stadtberge, at the boundary of the Rhenish schist mountains, and finally pass around the northern

[1] J. C. Freiesleben: 'Geogn. Beitrag zur Kenntniss des Kupferschiefergebirges,' etc., Geognost. Arbeiten, Vol. I–IV, Freiberg, 1807-1815. A. F. v. Veltheim: 'Ueber das Vorkommen der metallischen Fossilien in der alten Kalkformation im Mansfeldischen und im Saalkreis,' *Karsten's Archiv*, 1827, Vol. XV, p. 98 *et seq.* B. v. Cotta: 'Erzlagerstätten,' 1861, Vol. II, pp. 106-111. Schrader: 'Der Mansfelder Kupferschieferbergbau,' *Z.* f. d. B. H. u. S. im preuss. St., 1869, Vol. XVII, p. 251. F. Beyschlag: 'Geol. Karte der Mansfelder Mulde,' 1893. O. Speyer: 'Zechstein des westl. Harzrandes,' *Jahrb.* d. k. preuss. geol. Landesanst., 1880, p. 80. J. H. Kloos: 'Zechstein am nordwestl. Harzrand,' same journal, 1891, p. 126. Th. Liebe: 'Zechstein von Gera,' *Z.* d. D. G. G., 1855, p. 406. H. Bücking: 'Zechstein von Schmalkalden,' *Jahrb.* d. k. preuss. geol. Landesanst., 1882, p. 29. H. Pröscholdt: 'Zechstein am der Südosts. des Thür. Waldes,' same journal, 1886, p. 165. H. Loretz: 'Zechstein am westl. Thür. Wald.,' same journal, 1889, p. 221. 'Die Geschichte des Mansfeld'schen Kupferschieferbergbaues und Hüttenbetriebes,' Eisleben, 1900.

Spessart at Bieber, much farther south. The copper-bearing strata do not, it is true, show everywhere quite the same development and do not always carry a workable amount of metal. Their typical development as an ore deposit is at Mansfeld, on the southeastern edge of the Harz, the oldest and most famous copper mining district of Germany.

In the Mansfeld area the Zechstein formation rests unconformably on the Rothliegende[1], consisting essentially of red sandstones and conglomerates, the topmost layer of which, 1 to 1.5 meters thick, has been bleached, and hence is called Weissliegendes. The Zechstein is overlain by the Bunter sandstone. The formation is subdivided as follows:

Upper Zechstein	8.	Reddish or bluish clays with dolomite, gypsum, rock salt and potassium salts.
Middle Zechstein	7.	Fetid bituminous limestone.
	6.	Crystalline granular (Rauchwacke) and fine powdery (Asche) dolomite, 45 m.
	5.	Gypsum.
Lower Zechstein	4.	Zechstein limestone ..... .5–30 m.
	3.	Marly limestone..... .....0.75–1 m.
	2.	Hanging-wall bed (Dachklotz), a marly limestone crumbling into polygonal pieces when exposed to the air .....0.25m.
	1.	The copper shale bed .....0.5–0.6 m.

The copper-bearing rock is a bituminous, blackish marly shale with a greatly varying amount of copper. It possesses a fine slaty texture and is so hard that it sometimes rings when hammered. The rock contains an abundance of fossils, especially more or less mineralized casts of heterocercal ganoid fishes, particularly *Palaeoniscus freieslebeni* Ag., more rarely of *Platysomus striatus* Ag. and *Acrolepis asper* Ag. Further proof of its marine, non-lacustrine formation is furnished by the shells of *Lingula credneri* Gein, a brachiopod; it also holds water-borne ends of branches, fruits and leaves of two conifers, of *Ullmannia bronni* Göpp., and still more frequently of *Voltzia Liebeana* Gein.

The chemical composition of the copper shale may be judged by the limiting values of four analyses made by Scheerer of different samples of the unroasted material:

Silica	29.22–38.42
Alumina	11.28–15.93
Lime	10.93–14.39
Magnesia	2.25– 4.53
Carbonic acid	7.02–13.51
Iron	0.85– 3.31
Copper	2.01– 2.93
Silver	0.015–0.021
Sulphur	2.15– 4.97
Bitumen as loss in igniting	9.89–17.21

[1] "The name Rothliegende or rather Rothtodtliegende (red layer or red dead layer) was given by the miners because their ores disappeared in the red rocks below the Kupferschiefer." (Geikie.)

Zinc, lead, manganese, nickel and cobalt were not determined. In thin section under the microscope the rock shows a very fine sedimentary structure. Bright flakes with numerous clastic quartz grains and cross placed muscovite leaves occur between dark brown transparent layers rich in bitumen. The arrangement of the angular particles of ore conforms to this laminated structure.

The copper shale measure may be divided by its external appearance into several thin layers, to which the miners long ago gave distinctive names. The names used in the different districts are given in the following table:

	Hettstedt-Gerbstedt.	Eisleben.	Sangerhausen.
9	Oberberge.	Dachberge.	Noberge.
8	Noberge.	Noberge.	.....
7	Lochberge.	Kopf { Ober- / Unter- }	Unterwand.
6	Kammschale.	Kammschale.	Schieferkopf } about
5	Kopfschale.		..... } 10 cm.
4	Schieferkopf { Ober- / Unter- }	Grobe Lette.	Blattschiefer. }
3	Lochschale.	Feine (Loch) Lette	Schramschiefer } 5–6 cm.
2	Lochen.	{ (Wanting.)	..... }
1	Liegende Schale.		Erzschiefer. }

The rock of the lowest bed is clayey and soft. In the coarser middle division, the Kopschale and Kammschale, but especially the latter, show a well marked cross fracture, owing to their strings of gypsum. Finally, the layers of the upper division grow coarser in texture and grayer in color upward, heavier and more regularly fissile.

"The mineral content of the ore bed appears as a rule in the form of what is called *speise,* that is to say, it is disseminated through the rock in the form of very fine dust particles, which on cross fracture show a metallic lustre. The color is either golden yellow, indicating the prevalence of copper pyrite, or violet and copper-red, from the prevalence of bornite; more rarely it is steel-gray (indicating copper glance), at times yellow (indicating the prevalence of iron pyrite), at times lead-gray (indicating lead glance)." (From the company's publication.) Besides the sulphur ores just named, the speise (flawy earth) contains also argentite, zinc-blende, copper-nickel, cobaltic pyrite, all in very small amounts and in minute particles. Chemical analysis has also demonstrated the presence of minute quantities of manganese, molybdenum and selenium. Besides the speise, the copper schist also contains fine stringers of ore, mostly

parallel with the stratification, and consisting of bornite and glance, while the bedding planes show stains of copper glance, bornite, copper pyrite and native silver, also here and there stains and granules and nodules of ore, called 'Erzhiecken.' As a curiosity, the scaly coat of a fossil fish (*Palæoniscus*) was found coated with native silver, while ordinarily the coating on fish impressions consists merely of copper pyrite and iron pyrite. For that matter, it is not these striking concentrations of ore that determine the paying quality of the rock, but the contents of the speise.

Though the entire bed is copper-bearing, yet the paying ore is found as a rule only in the lower layers as far as the Kammschale, inclusive or exclusive of the latter. With the decrease of bitumen from that layer downward the ore content also decreases. Only in rare cases does the 'Kopf' also contain paying ore, so that the thickness of the paying strata on the whole is only 3.15 to 4.72 in., rarely 3.15 to 6 inches.

In the Sangerhausen district, the bed beneath the copper bed, that is the uppermost layer of the Weissliegende (a bleached red conglomerate), which has a thickness of ½ cm., sometimes 3 cm., is so rich in copper that it is mined under the name of 'sand ore' containing as much as 5 or even 10% of copper. Farther west, beginning between Sangerhausen and Steine, a layer of calcareous conglomerate is intercalated between the red conglomerate and the copper shale. This thin layer is also copper-bearing, sometimes in paying quantities, and is called zechstein conglomerate and locally shares the name Weissliegendes.

As already stated, the ore and metal content of the copper bed is not uniform throughout the region underlain by it. While in the Mansfeld district a 2 to 3% ore with ½ pound of silver in a centner of copper (5 kilograms silver per ton of copper) has since olden time been regarded as an average metal content, there are many exceptions. Thus, for example, the slates of the northern part of the district, those near Hornburg, contain hardly 1.5% copper. Outside of the Mansfeld area the mineral content decreases until the rock is completely barren. On the other hand, the miners have long been familiar with the fact that the copper content increases considerably near transverse fault fissures, called Rücken (ridges), and in the neighborhood of strongly folded zones, and that the enrichment extends upward to the higher layers of the measure, the Dachberge and the Faule, which in such cases also yield pay ore. The only exception is in the Hettstädt area, where the fissures are said to have an unfavorable influence on the metal content of the ore. The fissures themselves are either devoid of metal or contain rich ores, especially copper and nickel ores.

The section, Fig. 208, shows the dislocations found so frequently in the

Mansfeld copper 'schist,' and which are a very important feature. These dislocations consist of fissures called Sprügen (cracks) or Rücken (ridges), forming an angle with the strike of the measure, together with many folds and overthrusts parallel to the principal strike, and saddle-like elevations or 'mountains' (Bergen). Very often trench-like depressions have occurred between parallel cracks, such as the great Aa Fletzgraben (stratum trench) near Eisleben.

The Mansfeld copper schist mining works are said to have been begun in 1199 or 1200 at the town subsequently called Hettstedt. The barons of Mansfeld were probably granted the mining works as a fief only in 1364. In the 15th century the old records state the yearly production to have

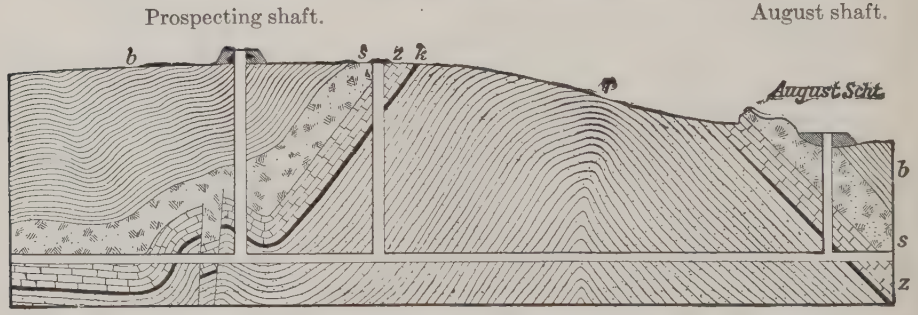


Fig. 208.—Profile of the eroded saddle (anticline) in the Tiefthal area of the Mansfeld district. (Schrader.)

b, Bunter sandstone; a, fetid stone and 'ashe'; z, Zechstein limestone; k, copper shale measure; r, Rothliegendes.

been over 20,000 hundredweight of copper. After the sequestration of the estate about 1570, and later during the Thirty Years' War, but little mining was done and the property was practically idle, which caused it to be thrown open to the public in 1671. Accordingly, in 1674, work was resumed by several corporations, which were in 1852 consolidated as the Mansfeldschen Kupferschiefer Bauenden Gewerkschaft, which is still flourishing. On June 12, 1900, the Emperor attended the 700th anniversary of the foundation of the Mansfeld mining industry.

The copper production, which for many decades has been steadily rising, was 19,050 tons in 1902; from 1779-1902 it was 476,000 tons. During its entire existence the Mansfeld mine has yielded about half a million tons of copper. The ore has averaged 27.76 kg. copper and 0.154 kg. silver.

Concerning the genesis of the copper ore of this formation, and the probable relation to the fault vein at Saalfeld, the reader is referred to what has been said on page 227. At this locality, as well as at the cupriferous slate beds of Ilmenau, Eisenach and Schmalkelden, on the edge of the

Thüringerwald, there is everywhere a significant and constant association of ore-bearing copper strata and ore-bearing fissures.

That the copper schist, considered as a mere sediment, is of little importance for its copper content, is shown by the totally different development of the copper-bearing Permian near Frankenberg in Kurhessen, where the copper ores occur in entirely different strata.

The copper-bearing Permian strata at Frankenberg[1], according to A. Denckmann, embrace the following beds:

4. The younger conglomerates.
3. The Permian sandstones with the Geismar copper clays.
2. The Stäteberg measure.
1. The older conglomerates.

The older conglomerates consist of red-brown sandstones with pebbly layers. In some parts the sandrock contains much feldspar and iron, with a calcareous or dolomitic cement. The "Stäteberg" formation cannot be accurately discriminated either from the conglomerates or from the overlying Permian sandstones, but must be regarded as a local, highly calcareous formation at the base of the last-named strata. Petrologically, it is composed of limestones, light-colored marls, clays and calcareous sandstones, with intercalated conglomerates. A characteristic feature is the presence of remains of plants, of gastropods, and of lamellibranchs, especially *Schizodus, Aucella, Gervilia, Pleurophorus,* etc. In connection with these organic remains, impregnations with copper ores and galena are to be observed.

The overlying strata, the Permian sandstones, attain a total thickness of at least 70 m. (229 ft.). They consist of reddish brown, in part bleached, highly feldspathoid sandstones, containing various layers of white limestone concretions, calcareous sandstones and sandy clays. The latter are often exceedingly rich in fossil plant remains, particularly *Ullmannia bronni* Copp., some araucarians and ferns, and in association with these they carry quite a high percentage of copper ore. One of these zones, called the 'Kupferlettenflötz' (copper clay measure), has a thickness of 12 to 15 in., sometimes reaching 18 in. The plant remains are for the most part completely mineralized, mostly by chalcocite; but also by native silver, pyrite, chalcopyrite, and more rarely by tetrahedrite, bornite and ruby silver. The mineralized remains of Ullmannia were called by the Frankenberg miners by the general name of 'Graupen,' and

[1] G. Würtenberger: 'Ueber die Zechsteinformation, deren Erzführung und den unteren Buntsandstein bei Frankenberg in Kurhessen,' *N. Jahrb.* f. Min., 1867, part I, pp. 10-38. A. Leimbach: 'Die permische Formation bei Frankenberg.' Marburger Dissert., 1869. E. Holzapfel: 'Die Zechsteinformation am Ostrande des Rheinisch Westf. Schiefergeb,' same, 1879. A. Denckmann: 'Die Frankenberger Permbildungen,' *Jahrb.* d. k. preuss. geol. Landesansto, 1891, p. 234 *et seq.*

went into the collections under the designations of 'Stangengraupen,' ears of corn, and 'Sterngraupen,' wings of flies, according to their forms and general appearance.

The ore is very irregularly distributed, occurring mostly in bunches. The average noted during a period of several years was 0.572 copper and 0.0013% silver.

Finally, the younger conglomerates are formed of well worn material, and are distinguished by the great amount of carbonates in their cement.

The series of sediments just mentioned lie more or less horizontally on the edges of steeply upturned strata of Devonian and Culm age. The different beds frequently overlap others of the same series. These copper-bearing beds are influenced by structural disturbances, which here have the same influence on the copper content of the sediments as the 'ridge' fissures (Rücken) of the Mansfeld area.

A different state of affairs obtains in the copper-bearing Permian at Bieber, at the northeast edge of the Spessart[1].

At that place a thinly stratified bituminous marl shale, 30 cm. (1 ft.) to 1.5 m. (5 ft.) thick, but very poor in copper, was worked for a long time, and was so soft that it could be mined with a pick. The ore contains tetrahedrite, chalcopyrite, galena and pyrite, and also carries cobalt ores near cobalt-bearing veins. This ore occurs in numerous small fissures which traverse the rock in all directions and at all angles, the most common being vertical. However, the ore is in many cases not limited to the Permian marl, but is also found in the underlying mica schist, where the latter is traversed by mineral veins. Similarly, on the border of the Rhenish Schiefergebirge, at Stadtberge in Westphalia, the copper ore, near vein fissures cutting through the bed, is to be found not only in the Kupferschieferflotz (copper shale) alone, but also in all the upper strata of the zechstein (Permian limestone), which there is 10-12 m. thick[2]; ore is also found in the Paleozoic graywackes and silicious schist beneath the ore-bearing bed proper.

Brief mention must also be made of an occurrence in the reverse direction, near Hasel and Conradswaldau in Lower Silesia, where five copper shale measures, lying close together, but carrying very little copper (1.5% on the average) occur intercalated in the dolomitic Zechstein limestone[3].

[1] Schmidt: 'Mineralogische Beschreibung des Biebergrundes.' *N. Jahrb.* f. M., 1808, p. 45. H. Bücking: 'Der nordwestliche Spessart.' Berlin, 1892, p. 133.

[2] E. Holzapfel: 'Zechstein am O.-Rande des Rhein.-Westf. Schiefergebirges.' Görlitz, 1879.

[3] H. v. Festenberg-Packisch: 'Met. Bergbau Niederschlesiens.' Vienna, 1881, p. 77.

1. *The Origin of the Copper Shale and Similar Formations.*

The 'Kupferschiefer' has for a long time been regarded as a typical example of an ore deposit formed by chemical precipitation of ores (from metallic solutions) during the formation of the rock by ordinary mechanical sedimentation in a large, enclosed marine basin, and under the influence of reducing organic substances. The waters were thought to have held metallic sulphates, accompanied by alkaline sulphates, such as are found in all sea water. The alkaline sulphates were supposedly first of all decomposed by decaying organic remains, with the development of hydrogen sulphide, and the latter then precipitated the metals from the solution as sulphides. Until the last few years[1], scientific opinion adhered to the old idea first made current by J. C. Freiesleben, viz.: that the fishes inhabiting the Permian seas, the Palæonisci and Platysomas, were poisoned by the solutions carried into those waters. The bodies of the fishes often found curled up as in convulsions and distinctly preserved in the fossil impressions, were supposed to prove this manner of death. The fish remains thus accumulated, together with the finely divided bitumen, were said to have been the principal reducing agents.

One part of this hypothesis, namely, the idea that the precipitation of the particles of ore in the copper shale was from aqueous solutions and was accomplished by a reduction due to bitumen, fish remains and other organic substances, may be supposed to be generally admitted. But the effective criticisms of F. Posepny[2], H. Louis[3] and other recent authors render it very doubtful, at any rate, whether the metallic minerals were segregated *simultaneously* with the deposition of the calcareous mud. At the present time, the weight of evidence seems even to prove the other possibility; that the marly shale was impregnated *after* its deposition, by metallic solutions rising through fissures. This may be shown by a brief discussion.

It is admitted that the ocean water of the present day contains small quantities of copper compounds. According to Dieulafait[4], the mother liquors of the salt flats (basins) of the Mediterranean contain so much copper that it can be demonstrated in as little as 5 cubic cm. of the liquid. One cubic m. of sea water would contain 0.01 gram of copper. According to Dieulafait, the black, sulphur-charged matter deposited in basins in which sea water is confined always contains copper. But how

[1] R. Brauns: 'Chemische Mineralogie,' 1896, p. 387.
[2] F. Posepny: 'Ueber die Genesis der Erzlagerstätten,' 1893, p. 168.
[3] Phillips and Louis: 'Ore Deposits,' 1896, p. 54.
[4] L. Dieulafait: 'Revue universelle des mines,' 1880, Vol. VII, p. 425.

are we to imagine that these minute quantities are to be concentrated in the mud settling mechanically in the sea, so as to form such percentages as we find in the copper schist? The hypothesis of the poisoning of the fishes is, in Posepny's opinion, very improbable, for the main argument, the "convulsive curvature," is characteristic of many fish impressions in sediments free from metals, such as the Solenhofen lithographic slate and the Tertiary shales of Monte Bolca. Moreover, even the marly slate of the English Permian limestone formation, quite similar to the 'Kupferschiefer' in other respects, but carrying no copper ores, contains the same curled-up Palæonisci. Evidently the curling up is a phenomenon accompanying the rigor mortis, such as may be observed after death in many fishes of the present time, when there has been no poisoning by metals. If the theory of fish poisoning by strongly metalliferous mineral water entering the sea is maintained, how often must this rare natural event have taken place to explain the formation of the entire thickness of the copper schist! For we know that this kind of fine sediment grows very slowly.

Again we have seen that the copper is to be found at *wholly different levels* of the Zechstein, in fact, that the *copper-bearing deposits of this formation cannot possibly be grouped as a stratigraphic unit.* Yet it was precisely the constancy of level that constituted, in A. von Groddeck's[1] view, the main argument for the theory of sedimentation.

It would seem that stress should rather be laid on the other observation: that, *wherever the formations comprehended under the name 'Kupferschiefer' are ore-bearing, the Zechstein and its underlying rocks are found to be traversed by numerous fissures, which have in part the character of mineral veins. The generally recognized fact that, with few exceptions, the amount of copper in the shale increases on approaching these fissures and dislocations, is direct evidence in favor of impregnation from the fissures,* particularly since it is found that the infiltration with copper compounds has affected not only the overlying and underlying beds, but extends as far down as the mica schist.

At any rate we are not yet justified in regarding the sedimentation theory as proved beyond question, as was done until recently. We prefer instead to await further scientific investigation before definitely adopting any one theory. The author had written the above passage in this form and had delivered it for several years in lectures, when F. Beyschlag[2] published similar conclusions, thus giving a new and effective support to these deductions.

[1] A. v. Groddeck: 'Lagerstätten der Erze,' 1879, p. 301.

[2] 'Beitrag zur Genesis des Kupferschiefers.' *Zeit. f. Prak. Geol.*, 1900, p. 115.

2. *Copper Ores of the Permian Red Beds (Rothliegende) of Northeastern Bohemia.*

At various points in northeastern Bohemia[1], at entirely different geologic horizons, the Rothliegende formation contains beds impregnated with copper ores, which here and there occur in paying quantities. The best known localities are Strabacov and Kosinetz near Starkenbach, Oberkalna, Eipel, Wernersdorf near Radowenz, Böhmisch Brod and Schwarzkostelez. At Wernersdorf the ores are found in two horizons, in a clay slate above and another clay slate below a thick bed of conglomerate. Below the zone of weathering, the ores consist of finely divided copper glance. Concretions also occur that are often as large as the palm of the hand, containing copper glance inside, which gradually passes over into pyrite. Such kidneys contain as much as 14% of copper. From the vicinity of Radowenz, calamites have been obtained, consisting of a mixture of anthracite and copper glance. Their striped surfaces bear a thin coating of malachite, azurite and clay. These oxidic ores are to be noted in fissures within these calamites, whose total copper content amounts to 32 to 50%. As late as 1891, Bohemia produced 2,400 tons of copper ore.

Similar deposits have been found in the country about Jauer in Silesia.

3. *The Copper Deposits in the Permian Formation of Russia.*

According to Nikitin[2] and other Russian geologists, the Permian formation whose nearly horizontal beds cover a vast area west of the southern Ural is divided as follows:

4. Red sandstone, variegated marls and clays of the Tartar stage, which represent a transition to the Triassic.

3. A group of strata consisting essentially of limestones, corresponding to the Zechstein of western Europe (with *Leda speluncaria, Turbonilla altenburgensis, Macrodon kingianum,* etc.).

2. Sandstones, limestone, marl and clay shales, with intervening copper-bearing beds (with *Spirifer rugulatus, Productus cancrini, Strophalosia horrescens,* etc.).

[1] O. Polak: 'Geogn. Bericht über die im Bunzlauer, Jitschiner und Königsgrätzer Kreise unternommenen Schürfungen.' *Jahrb.* d. k. k. geol. Reichsanst., 1858, p. 239. C. A. Hering: 'Die Kupfererzlagerstätte der Dyas im norsdöstl. Böhmen in Bez. auf ihre Abbauwürdigkeit.' *Oesterr. Z.* f. B. u. H., 1888, pp. 676–678. F. X. M. Zippe: *Sitzb.* Ak. d. Wiss., Vol. XXVIII, p. 192 *et seq.* G. Gürich: 'Die Kupfererzlagerstätten von Wernersdorf bei Radowenz in Böhmen.' *Zeit. f. Prak. Geol.*, 1893, p. 370 *et seq.*

[2] S. Nikitin: 'Recherches géolog. le long de la ligne du chemin de fer de Samara.' *Bull.* du Com. Géol. St. Pétersburg, 1886, Vol. V; 1887, Vol. VI, p. 225. Tschernyschew: 'Une excursion dans le gouv. Oufa et de Viatka.' Same, 1887, Vol. VI, p. 7; 1888, Vol. VII, p. 81.

1. Clayey limestones, marl and gypsums of the lowest horizon.

This shows that the copper-bearing strata occupy about the same stratigraphic position as the 'Kupferschiefer' of Germany. The Permian of the Ural contains similar copper deposits, especially in the districts of Perm and Ekaterinburg, as well as farther south in the districts of Ufa and Orenburg. It has been found that in these regions the richness of the ore decreases as one recedes from the Ural, ceasing entirely at a distance of about 500 km. (300 miles). Furthermore, it is stated that while the copper is especially concentrated around the impressions and carbonaceous remains of calamites, it also occurs in fine dustlike particles, in nodules and tufts and in small fissures. The sandstones in particular carry the ore. The ore consists chiefly of malachite, azurite, earthy red oxide of copper, and brick ore (ziegelers), as well as of copper glance, especially in the fossil remains of plant stalks. More rarely bornite, cuprite, volborthite (a basic copper vanadinate), gypsum and calcspar make their appearance[1].

The distribution of the ore is exceedingly irregular, and is limited to beds 6-70 cm. (0.2 ft.-2.3 ft.) thick, 2 to 4 of which may occur one above the other. The copper averages about 3%. The most important works are situated in the steppe of Kargalinsk, 40 km. (24 miles) from Orenburg.

The Permain formation in the Donetz area, east of Bachmut[2], also contains such deposits, which, though very poor, were worked as early as the Stone Age. They consist of grayish white sandstones, impregnated with copper ores, which are overlain by red clays and sandstones forming the base of the Permian.

4. *Copper Ores in the Permian of Texas and Nova Scotia.*

According to E. J. Schmitz[3], the Permian formation in the Red River and Brazos River districts of Texas consists of slightly inclined or horizontal strata of sandstone, clay slate, marl and conglomerate, certain beds of marl and clay slate being impregnated with copper ore, at widely different horizons and at numerous points scattered over a rather extensive area. The ores are mainly green and blue silicates and oxides. They are found especially in the form of fossil wood, in log-shaped pieces, with a

[1] E. Neubert: 'Die Kupfererzlager der Kargalinskischen Steppe.' *Berg u. Hütten Zeit.*, 1863, pp. 141, 169. C. R. Förster: 'Notizen über den Kupferbergbau der Karkalinskischen Steppe.' *Idem*, pp. 193–195.

[2] A. Reh: 'Das Kupfererz- und Salzvorkommen in der Permischen Formation Südrusslands.' *Z.* f. B. H. u. S. in Preussen, 1881, Vol. XXIX, p. 276.

[3] E. J. Schmitz: 'Copper Ores in the Permian of Texas.' *Trans.* Am. Inst. Min. Eng., 1897, Vol. XXVI, pp. 97–108.

diameter of several centimeters, but also as finely interspersed particles and as rounded concretions. The mineralized logs and the concretions contain 20-60% copper, the entire masses enclosing them carrying for the most part but 3.5-5%, the finely impregnated strata as a rule much less.

Closely analogous deposits have been described by H. Louis[1] from the Permian of New Annan on French river in Nova Scotia, the chief difference being that the copper ores there consist mainly of copper glance, more rarely of copper pyrite, indigo copper, etc.

5. *The Copper Deposits of Corocoro in Bolivia.*

Corocoro lies in the Serrania de Corocoro-Charcarillo, which rises, island-like, from the high plateau of Bolivia south of Lake Titicaca[2]. The high plateau itself extends from the Andes on the west, which are formed of Jurassic strata with numerous eruptive stocks of Tertiary age, to the Cordillera Real on the East. The latter range consists of Paleozoic schists with numerous trachyte and porphyry dikes. The plateau is entirely covered with Pleistocene sands, clays and drift. Only in the neighboring mountains do the Permian bed rocks crop out. The Permian formations consist of clays, argillaceous shales and breccia-like conglomerates and sandstones, cemented by calcareous material rich in iron. The strata are almost all red. The clays and shales also contain layers and strings of gypsum and a little rock salt.

The mountain village of Corocoro is situated in a deep-cut valley on the west side of the Serrania. The copper-bearing measures worked in the neighborhood of the town belong to the Permian formation just described. They consist of ash-gray, fine-grained to coarse-grained sandstones and fine sandstone conglomerates, stained by patches and disseminated grains of blue, gray, green and black ore. According to H. Reck[3], whom we follow, the measures have an average thickness of 0.5-2 m., and carry native copper in grains, in massive plates up to one foot in thickness, and in masses with the form of hair, wire, moss, shrubs, branches, leaves and fine crystals; also in pseudomorphs after aragonite crystals. The principal bed, Buen Pastor, does indeed grow to be as much as 12 m. thick, but its brown-red rock is in the main devoid of ore, only the gray or green spots in it containing ore in paying amount. In the lower parts, this bed also contains native copper and some native silver, while the upper portions

[1] H. Louis: Discussion of the paper by Schmitz, *op. cit.*, p. 1051.

[2] David Forbes: 'Geology of Boliva and Southern Peru.' Quarterly Jour. Geol. Soc., London, Vol. XVII, 1861, p. 41.

[3] H. Reck: 'Das Vorkommen u. s. w. des Kupfers in der Serrania de Corocoro-Chacarilla.' *Berg u. Hütten. Zeit.*, 1864, pp. 93–96.

contain malachite, red copper ore, copper arsenide, azurite, etc. The ores are always accompanied by gypsum. The large, wavy copper plates, called *charque* (air-dried meat), are sometimes entirely enveloped in gypsum. Mention must be made of the occurrence of bones, whose marrow cavities are filled with native copper, and of mineralized wood remains. The strata are traversed by fault fissures.

Copper was mined on the Bolivian plateau as early as the time of the Incas. Modern mining dates only from 1832, the town of Corocoro being founded in that year. In the nineties the average yearly production of the copper mines of the Corocoro district was 2,300 tons of copper. In the sixties, on the contrary, the average annual exportation from the district was 3,000-3,500 tons copper and 25 tons silver.

6. *Copper Ores in the Bunter (Triassic) Sandstone Formation of Saint Avold and Wallerfangen.*

In the district of St. Avold and Wallerfangen near Saarlouis in Lorraine, the Bunter sandstone formation is divided as follows:

Upper Bunter sandstone or Voltzia sandstone.	7. Shelly limestone, with gypsum in its lowest part. 6. Red clays and sandstones of the Rothliegende. 5. Fine-grained sandstone, the so-called stone-breakers' bed, with intercalated clays and plant remains; in places with copper ores, about 12 m. 4. Drusy, iron-charged sandstone with dolomite lenses, 6 m. 3. Red clay layer with dolomite lumps, a few centimeters. 2. Conglomeratic sandstone, here and there with copper ore, up to 9 m. 1. Principal variegated sandstone or Vosges sandstone, more than 300 m.

The ore is restricted to that portion of the sandstone beds immediately overlying and underlying the two dolomite-bearing beds. Where ore exists at all, it impregnates layers only 6-60 cm. thick[1].

It consists of an impregnation with malachite and earthy azurite, and in the lower horizon also with earthy black oxide of copper. At certain points the copper ores are replaced by lead ores, galena and lead oxide. The ore minerals occur as minute grains or films, dusted over the surfaces of small fractures, and as nodules sometimes as large as a walnut, and are often found replacing the woody parts of fossil plants.

The ore-bearing rocks are restricted to certain zones, separated by barren rock. These zones, as a rule, run parallel to the strike, and seem to be connected, especially at Saint Avold, with the anticlines of the Bunter

[1] Jacquot: 'Notice historique et géologique sur les mines de St. Avold,' etc. *Ann.* de l'ac. de Metz, 1857. C. Simon: 'Kupfer- und Bleierzablagerungen im bunten Sandstein, etc., von Saarlouis und St. Avold.' *Berg u. Hütten. Zeit.*, 1866, pp. 412, 421, 430. Hauchecorne: 'Ueber Bleierze aus dem Bunstsandstein von Saint-Avold.' *Z.* d. D. G. G., 1879, Vol. XXXI, p. 209.

Sandstone strata, for they here coincide with the side of an anticline dipping west and southwest. But even within these zones the horizons mentioned above are impregnated with ore only where one of the numerous north-south fissures cuts through the zones.

This appears from the ground plan and section given in Fig. 209. Such fissures were disclosed, for example, a half century ago in the Barbara mine near Wallerfangen. According to C. Simon, they formed open clefts, often an inch across and mostly dry, whose sides were ornamented with magnificent green and blue stars of concentric-radiating crystals of malachite and azurite. Sometimes the fissures were closed and not infrequently filled entirely with compact azurite and malachite. In fact, the entire area of Bunter Sandstone is strongly fissured. Some fissures cause considerable dislocations, for example, the one which runs from west-eastward from Quatre Vents, south of Longeville, across the Kreutzberg, toward the Heiligenborn, near Saint Avold. In the immediate vicin-

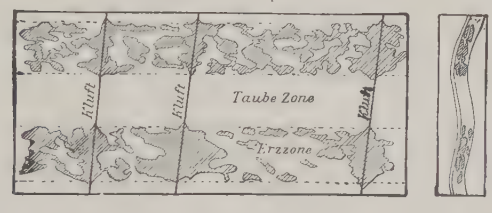


Fig. 209.—Ground plan (a) and elevation (b) of the ore deposit of Wallerfangen and Saint Avold, showing the arrangement of the ore zones and fissures (kluft). Taube zone = barren zone; Erz-zone = ore-bearing zone. (C. Simon.)

ity of this fissure, which throws the Muschelkalk down to the level of the Bunter Sandstone, we find in the former the lead deposits of the Castelberg near Longeville, the copper ores in the Hochwald, the rich calcareous lead-bearing rocks in the Bleiberg near Saint Avold, and finally the copper ores of Helleringen. The Heiligenborn, a chalybeate sour spring, issues from this same fault line. It seems also that this line of earth movement continues across Cocheren to beyond the Schlossberg near Forbach. It would thus take in the warm saline spring of Cocheren.

In the Hochwald another fissure, striking north-south, is noteworthy. It dips east at an angle of 70° and the copper ore bed shows a vertical displacement of 2 m. The fissure is 4.5 m. wide, and is filled with copper ore, barite and red silicious iron ore. However, the ore is limited to the ore zone at that place, and to the level of the ore-bearing bed.

The genesis of these ore deposits is ascribed by C. Simon to a precipitation simultaneous with sedimentation, although the conditions described

by him in detail, and just summarized, seem to indicate ore deposition by subsequent infiltration of ore solutions as more probable.

The copper mining operations of Wallerfangen may be traced back to Roman times. From 1500 on, azurite in particular was exported to Italy for painters' colors. Subsequently the mining operations ceased, but were resumed in the fifties.

Triassic sandstone impregnated with copper ore is also known to occur at Twiste[1] near Arolsen, where there are four beds with copper glance and malachite; also at Bulach[2] in the Black Forest of Wurtemberg (where it is associated with gray copper ore), and at Büdingen[3] in the Grand Duchy of Hesse.

7. *Copper-bearing Triassic Sandstones in New Mexico.*

In the Nacimiento mountains, which extend with a north-south course through the northwest part of New Mexico west of the headwaters of the Rio Grande del Norte, the mountain core consists of granite. This is overlain by essentially calcareous strata of Carboniferous age, followed by white and red Triassic sandstones, marls and gypsums in steeply upturned beds overlain by Cretaceous strata[4].

The Triassic sandstones and conglomerates, whose age is shown by cycad remains, especially *Podozamites crassifolia,* contain certain beds rich in copper ores. The copper occurs in intimate connection with the numerous leaves, stalks and stems of the plant remains mentioned. The ores are principally bornite, copper glance and melaconite (black oxide of copper). They appear interspersed throughout the entire thickness of the sandstone deposit, which is 20-30 m. (65 ft.-98 ft.) thick, but are found concentrated only in scattered patches in the joints between the strata, as well as in whole beds of the above mentioned plant remains. The ores also contain a very small amount of silver.

8. *Copper-bearing Sandstones of the Copper Basin, Arizona.*

A deposit closely resembling that just noted, but without the plant remains, occurs at Copper Basin, Yavapai county, Arizona. A coarse-grained granite, traversed by porphyrite dikes and a great quartz vein,

[1] B. v. Cotta: 'Erzlagerstätten,' Vol. II, pp. 165, 211.

[2] Quenstedt: 'Epochen der Natur,' p. 469.

[3] C. Simon: 'A. a. O.', p. 412.

[4] J. S. Newberry: *Rep.* of Exploring Exped. in 1859. Washington, 1876. F. M. F. Cazin: 'New Mexico and Lake Superior as Copper Producers,' *The Engineering and Mining Journal,* 1880, p. 87. *Ibid.*, 'Genesis of Ore Deposits,' 1902, pp. 210, 251.

is covered by conglomerates, breccias and sandstones, of uncertain age, in part dissected into isolated blocks. These beds contain azurite and malachite in the cementing material and also as incrustations around the grains and pebbles of the sandstones and conglomerates. The percentage of copper is stated to be 12-15% throughout beds 1 to 3 m. thick. The underlying granite also carries some copper ore, in its uppermost part, as veinlets and impregnations of malachite and cuprite, while at great depths copper pyrite occurs associated with quartz. It thus seems certain, as W. P. Blake[1] pointed out, that the sandstones received their metal contents found below subsequent to their deposition.

9. *Copper Ores in the Cretaceous of Angola.*

Conglomerates strongly impregnated with copper ores have recently been found at Senze do Itombe, in the Portuguese colony of Angola, West Africa. According to F. W. Voit's[2] investigations they are intercalated in the Cretaceous limestones and various sandstones, which have a dip of 12° southwest, resting against crystalline schists of the higher ground inland. The beds above and below the conglomerates consist principally of magnificently crystallized malachite, and azurite, accompanied, according to Voit, by volborthite, chrysocolla, calcite, aragonite, and barite. These ores are partly replaced in depth by copper glance accompanied by a little galena. It is probable that this rich deposit will be worked very soon, as it is situated near the railway and only 20 kilometers from the navigable Cuanza river.

10. *The Bedded Copper Deposits of Boleo, Lower California, Mexico.*

Boleo lies on the east side of the Peninsula of Lower California, opposite the Port of Guaymas on the Sonoran coast. According to E. Fuchs[3], the region is part of an extensive plateau, built up of well bedded trachytic and andesitic tuffs and conglomerates, of Miocene age, the strata being gently inclined towards the sea. An isolated dome rises above this tract. The plateau is scored by four deep gorges. The entire series of tuff beds is partly covered by a vast basalt sheet. On the west the plateau abuts against a trachytic mountain range running along the coast (Fig. 210).

[1] W. P. Blake: 'The Copper Deposits of Copper Basin, Arizona, and their Origin.' *Trans.* Am. Inst. Min. Eng., 1889, Vol. XVII, pp. 479–485.

[2] F. W. Voit: 'Die Kupfererzvorkommen bei Senze do Itombe,' etc., *Zeit. f. Prak. Geol.*, 1902, pp. 353–357.

[3] E. Fuchs: 'Notes sur les gisements de cuivre du Boleo.' Assoc. Franc. pour. l'avancem. des sc., 1885. Fuchs and De Launay: 'Traité,' etc., 1893, p. 349. P. Krusch: 'Kupfererzlagerstätten in Nieder Calif.,' *Zeit. f. Prak. Geol.*, 1899, p. 86.

The copper ore is found in three separate beds, the lowest 0.6-3 m. thick, the middle 0.8-2.3 m., the upper on an average 1 m. The beds are largely composed of a clayey tuff of grayish lilac color, containing 0.1-6% salt (NaCl). The ore is scattered through this clay in the form of granules, small fragments, or rounded concretions, which at the base of the bed are always concentrated into a compact layer 15 to 20 cm. (6 to 8 in.) thick. The ore consists of cuprite, with some atacamite, azurite, malachite, chrysocolla and crednerite ($Cu_3Mn_4O_9$). Owing to the rather abundant admixture of crednerite, the analysis of the ore shows besides 15-26% copper and 4-12% Fe_2O_3, a large amount (7-24%) of manganese (P. Krusch).

The middle bed, which is especially rich in silica in the neighborhood of a transverse fault, probably as a result of impregnation by hot spring waters, is remarkable for its abundant oolitic concretions of oxidic and carbonatic copper ore, called *boleos*. These concretions contain 25-40%

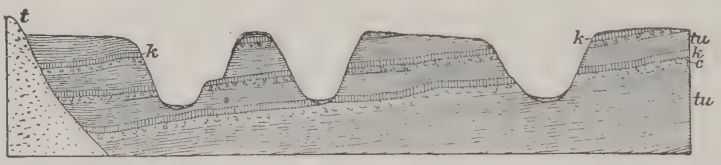


Fig. 210.—Diagrammatic section through the copper deposits of Boleo, Lower California, Mexico. (Fuchs.)
t, trachyte; tu, clayey tuffs; c, conglomerates; k, copper beds.

copper and attain a diameter of several inches. In the lowest bed, copper glance and covellite occur[1].

The deposits began to be worked in 1884. The production was:

1898: copper 9,857 tons, ore 192,000 tons.
1902: copper 10,956 tons, ore 275,635 tons, averaging 3.95% Cu.

(c) Lead Deposits.

1. *The Nodular Ores of Commern in the Rhine Province.*

The lead ores of this district are found in sandstone beds that form part of the Triassic series known as the Bunter sandstone. This formation lies above the strongly folded and upturned Devonian (Rhenish schist), near Commern, between Aachen and Bonn, to the north of the Eifel mountains. The sandstone strata extend over a length of about 3 miles and a breadth of one mile, and are in part overlain, conformably by the Roth and Muschelkalk. The lead ores occur in the lower beds of the so-called Haupt-

[1] *The Engineering and Mining Journal*, 1903, Vol. LXXVI, pp. 366, 765.

buntsandstein, constituting the lower division of this Bunter formation. The Knottenflötze (nodular ore measures) of the Bleiberg belong to the Meinertzhagener Bergwerksactiongesellschaft and some neighboring mining

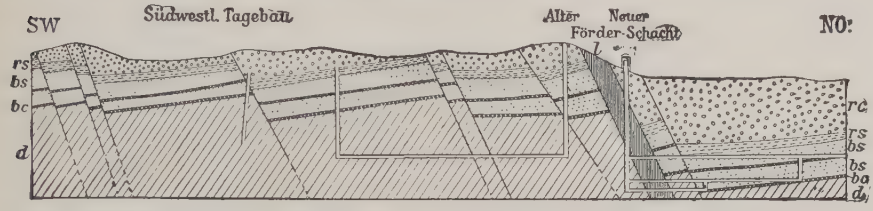


Fig. 211.—General section through the lead ore deposits of Griesberg, near Commern. (Blanckenhorn.)

rc, red conglomerates; rs, red sandstones; both overlying (upper Hauptbuntsandstein); bc, conglomeratic horizons of the lower Hauptbuntsandstein (Wackendeckel); bs, lead-ore bearing, bleached sandstones (nodular measures); d, Devonian graywackes; l, clayey and sandy fillings of a fissure of displacement.

grants. These deposits are worked, between Call and Mechernich, over an area one mile long and ¼ mile wide[1].

In the region of the Bleiberg, the sandstone strata dip northwest at 5 to 12°, but the beds are broken and greatly disturbed by innumerable faults. In

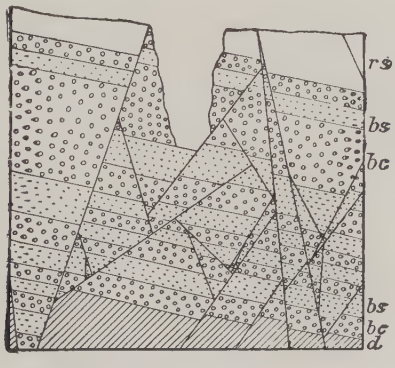


Fig. 212.—Section through a greatly disturbed part of the lead deposits of the Schunk Olligschläger grant. (Hupertz.)

many places the nodular measures are literally chopped up by these faults. The two sections, Fig. 211 and 212, exhibit the structure of a less disturbed and of an unusually disturbed part respectively.

[1] C. v. Oeynhausen and H. v. Dechen: 'Der Bleiberg bei Commern.' *Karstens Archiv*, 1825, Vol. IX, pp. 29–40. C. Diesterweg: 'Beschreibung der Bleierzlagerstätten, des Bergbaus und der Aufbereitung am Bleiberge bei Commern.' Z. f. B.-, H.- u. S.-W. im preuss. St., 1866, pp. 159–196. M. Blanckenhorn: 'Die Trias am Nordrande der Eifel.' *Abh.* zur geol. Spezialk. von Preussen, 1885, Vol. VI, p. 2. F. W. Hupertz: 'Der Bergbau, etc., des Mechernicher Bergwerks-Aktien-Vereins.' Köln, 1886.

The two most important displacements are the Griesbacher fault, which, with its accompanying parallel side fractures, displaces the measures in step faults for 42-46 m. (138-151 ft.) and the Sonnenberger fault, which is filled with barite and shows splendid slickensides. The latter fissure, according to M. Blanckenhorn, may have a throw of 140 m. (460 ft.) It forms the boundary of the Bleiberg proper at the South.

The Bunter formation of this region contains, especially in the lower horizon, many intercalated conglomeratic beds (called Wackendeckel). The pebbles of the rock consist of quartzite, graywacke, sandstone and quartz. These conglomerates vary greatly, both in their relative position and in their thickness, so that no section can be given that will apply to all the mines.

At Mechernich the following series of beds occur over a considerable distance:

Drift sheet
Red sandstone
Conglomerate
Yellow sandstone
Conglomerate
Clay
} These upper beds attain a maximum thickness of 50 m (164 feet).

Upper nodular layer, 26 m.
Conglomerate.
Lower nodular layer (18 m.), but often with 3 to 4 congl. layers.
Bottom conglomerate, 0.5 to 6 m.
Red clay with fragments of greywacke.
Devonian country rock (lower Devonian).

At Griesberg, near Commern, the following section occurs (according to M. Blanckenhorn):

Cover of drift and soil.
Conglomerate with red sandstone intercalations (upper Hauptbuntsandstein, devoid of ore) ..... 3 m
First nodular measures in the upper third reddish-yellow sandstone devoid of ore, with merely barren nodules, in the lower part *white* and carrying ore ..... 9.0–11 m
Conglomerate (Wackendeckel) ..... 0.6– 2 m
Second nodular measure, with lead ore nodules, in places also with oxidic copper ores ..... 10 m
Basal conglomerates, in places with galena and malachite ..... 2.0– 4 m
Devonian formations.

The nodular measures consist of a whitish, mostly readily friable sandstone, composed of quartz grains of the size of a millet seed, held in a clayey or slightly calcareous cement. The nodules (Knotten) of lead ore occur scattered, close-crowded or united into rounded concretions, 1 to 3 mm. in diameter, formed of sand and galena, more rarely also of cerussite, or, at the Griesberg, of oxidized copper ores. Through the crystallization force of the galena, they have at times assumed hexahedric outlines, or well formed cubes may project from them. Wherever these ore nodules occur, the sur-

rounding sandstone is whitish through bleaching. Organic material no doubt effected not only this reduction of the ferric oxide, which elsewhere colors the sandstone, to ferrous oxide, but also induced the segregations of the lead sulphide from solution.

Besides the nodules of lead ore, barren nodules also occur, concretions whose cement is merely clayey or calcareous.

According to F. W. Hupertz the material obtained by washing consists of 98 parts of coarse-grained nodules with a lead content of 20 to 24%, and of two parts of fine-grained smelting ore with 55-60% lead.

At Bleiberg, according to C. Diesterweg, in the workable portions of the ore bed the nodules form 4-10% by weight of the entire mass of the measure. The average lead content of the workable measures is 1.5-2%, and the silver content is stated at 1 to 6 grams per ton. The lead is, however, not always concentrated into nodules, but often occurs as cerussite uniformly distributed throughout the sandstone as a cement between the quartz grains. Sometimes cerussite also forms a crust, probably of secondary nature, around the galena nodules.

Nodules of lead ore and copper ore but rarely occur together. In the mining districts of Günnersdorf and New-Schunk Olligschläger, occasional patches occur which contain nodules of copper ore whose green color contrasts sharply with the rest of the mass, which is studded with blue-gray lead ore nodules. Galena is also found in the conglomerate (Wackendeckel), sometimes finely crystallized, but not in workable amount.

Somewhat different conditions prevail at the lead deposits north of the Tanzberg near Keldenich, the so-called Lehmerzlager (clay ore beds). The ore beds are brownish-red clays containing thin layers of fibrous lead carbonate (banded ore) or clayey concretions of ore (hepatic ore). As they are intercalated between the two variegated sandstone strata, they belong to a higher horizon than those mentioned above

Finally, mention must be made of the faults, which cut the sandstones and conglomerates, cutting clean through the quartz pebbles of the latter rock. These fissures contain galena and cerussite both well crystallized, together with pyromorphite, pyrite and chalcopyrite.

The origin of these stratified lead deposits has usually been ascribed to a segregation of the galena during the deposition of the sandstone.

The more probable theory advocated by Posepny[1] is that the ore was deposited secondarily in the greatly dislocated sandstone strata by uprising springs following the faults. He points out the significant fact that, while the nodules as a rule are arranged parallel to the stratification, yet close to the fault fissures which cut through the sandstone the nodules are

[1] F. Posepny: 'Genesis,' 1893, p. 173.

grouped in zones parallel to the walls of the steeply dipping fissures. The correctness of this reasoning is confirmed by the vein-like deposits of galena, in the Devonian Eifel limestone of the neighboring Tanzberg, near Keldenich, worked by the ancient Romans. Along the bedding plane between the Bunter sandstone and the Eifel limestone, the deposits just named become enlarged to regular funnels, filled with a crumbly efflorescent clayey iron ore, rich in manganese, and carrying copper and lead ores with iron pyrite.

The iron industry of the Mechernich district also dates back to Roman times. At that time, besides the lead ores in the Devonian limestone of Tanzberg, the more compact galena ores of the Wackendeckel were mined. On the other hand the exploitation of the nodular sandstone began in 1629. For many years subsequent to 1852, it was partly carried on by open cuts, but the recent work is all underground. In the seventies the production of lead was 10,000 to 15,000 tons, that of silver 2,300 to 3,700 kilograms per year. In 1900 Mechernich produced 262,126 cubic meters of nodular sandstone, which yielded 22,145 tons of ore (1 ton of ore to 11.84 cubic meters of material extracted).

Lead ore impregnations also occur in the Triassic sandstone at Saint Avold near Saarlouis, alongside of the copper ore impregnations mentioned on page 500. They are exclusively confined to the immediate vicinity of faults. According to Fuchs[1] the ores of the Bleiberg near Saint Avold also contained 560 grams of silver per ton of lead.

2. *Lead Ores of the Triassic Sandstone at Freyhung in the Oberpfalz of Bavaria.*

At Freyhung, the headwater region of the Vils, north-northeast of Amberg, and further northeast near Pressath in the Valley of the Naab, the Keuper formation found in the mountains forming the eastern border of Bavaria contains lead deposits along the Freyhung-Kirchenthumbach displacement[2]. The Keuper of that locality is divided into:

3. Rhaetic (yellowish-white sandstones and clay slates).

2. Keuper (Gyps Keuper; bright red, green and mottled marls, clay and sandstones).

1. Kohlen Keuper.

In the lower part of the Keuper formation there are intercalations of white, kaolinous sandstones with pockets and impregnations of fine-

[1] Fuchs and De Launay: 'Traité,' 1893, Vol. II, p. 658.

[2] B. v. Cotta: 'Erzlagerstätten,' Vol. II, p. 192. K. Gümbel: 'Ostbayerisches Gerenzgebirge,' p. 687. F. Posepny: 'Genesis,' 1893, p. 173. E. Kohler: 'Die Amberger Erzlagn.' Geog. *Jahrb.*, Munich, 1902.

grained galena and lead carbonates and efflorescent ore, as well as layers of clay impregnated with cerussite. The principal bed is from 1 to 3 m. thick, and consists of a white friable sandstone, containing an average of 5-10% cerussite and galena. The ore mostly occurs associated with plant remains in the Keuper sandstone, especially fragments of tree trunks. F. Posepny figured a cross-section of a mineralized trunk, which has been for the most part transformed into galena, while, in the bark, iron pyrite has been deposited.

The lead mining industry was formally productive at Freyhung, and was resumed in the eighties at the Vesuv mine by the Bavarian Lead Mining Company.

(d) Silver Deposits.

The Silver Sandstones of Utah.

In Washington County in the State of Utah, near the Arizona boundary, the prevailing Triassic formation consists of highly inclined strata of slate and sandstone. Two of the beds known as the White Reef and the Buckeye Reef consist of whitish gray or reddish brown sandstones, which contain many indeterminable plant remains, and are, according to C. M. Rolcker, and others, impregnated in many places with silver chloride and some native silver, so that the silver content amounts to 0.085%. At lower horizons, rich silver sulphide and copper ores also occur.

While J. S. Newberry considered this ore to have originated simultaneously with the sandstone, most other authors are of the opinion that the ore was introduced secondarily. C. M. Rolcker[1] bases his belief especially on the fact that the sandstone is richest near fault fissures, which, beside the clays, sometimes also contain silver ores. For that matter, in one end of the same sandstone bed rich zones are separated from one another by broad intervening streaks of barren rock.

(e) Stratified Gold Deposits of Paleozoic Formations.

1. *The Gold-bearing Conglomerates of the Witwatersrand, South Africa*[2].

Of all the stratified gold ore deposits of the globe, the conglomerate beds of the Witwatersrand, or of the Rand, as it is most commonly called, in

[1] Ch. M. Rolcker: 'The Silver Sandstone District of Utah.' *Trans.* Am. Inst. Min. Eng., 1880, Vol. IX, p. 21. R. P. Rothwell: 'The Silver Reef District, Southern Utah,' *The Engineering and Mining Journal*, Vol. XXIX, pp. 25, 48. J. S. Newberry: *Rep.* of the Stormont Silver Mining Co., *The Engineering and Mining Journal*, Vol. XXX, p. 269.

[2] The most important publications on the Rand are: E. Cohen: 'Goldführende Conglomerate in Südafrika.' *Mitth.* d. naturw. Vereins f. Neuvorpommern und Rügen. Also 'Geogn.-petrogr. Skizzen aus Südafrika II.' *N. Jahrb.* f. Min., 1887, Vol. V, p. 210. A. Schenk: 'Ueber das Vorkommen des Goldes im Transvaal.' *Zeit.* d. D. G. G., 1889, Vol. XLI, p. 573 *et seq.* W. H. Penning: 'A Contribution to the Geology

the Transvaal, are of the greatest scientific and economic importance. Accordingly they are the subject of many scientific works, from the most important of which we cull the following description:

The Witwatersrand forms the north edge of the so-called Hoogeveld, an indented line along which the undulating plateau drops steeply down to the much lower hilly country about the capital, Pretoria. The lowest part of this scarp is formed of granite and crystalline schists, the upper of clay slates and quartzites of the Barberton series, the two together representing the South African Primary formation. On these rocks is superimposed, probably uncomformably near the edge of the plateau, the Witwatersrand formation, whose age has not yet been determined with perfect certainty, though G. A. F. Molengraaff regards it provisionally as part of the Primary formation. This is in turn overlain, as has been recently demonstrated, by the overlapping Devonian 'Cape formation.' The latter is divided, from below upwards, into the Black Reef strata (=Table Mountain sandstone), the Malmani dolomite and the slates and quartzites of the Gatsrand, also called Pretoria series or Magalies strata, in turn overlain, unconformably, by the horizontal, coal-bearing Karroo formation of upper Carboniferous to Permian age.

These relations are exhibited in the section, Fig. 213. This also shows that the top of the Witwatersrand formation is formed by a sheet of diabase amygdaloid, 400 to 700 m. thick, and that the strata are arranged in the form of a synclinal basin, whose south side has been subjected to many disturbances.

In these statements we are following the facts presented by the Geologic

of the Southern Transvaal.' *Quart. Journ.* Geol. Soc., 1891, Vol. XLVII, p. 452. W. Gibson: 'The Geology of the Gold-bearing and assoc. Rocks of the Southern Transvaal.' *Quart. Journ.* Geol. Soc., 1892, Vol. XLVIII, p. 420. F. Abraham: 'Aufrichtige Geschichte der Goldminen des Witwatersrandes.' Berlin, 1892. L. de Launay: 'Nouveaux gisements d'or du Cap.' *Bull.* Annales des mines, 1892, p. 136. G. A. F. Molengraaff: 'Beitrag zur Geologie der Umgegend der Goldfelder auf dem Hoogeveld,' etc. *N. Jahrb.* f. Min., 1894, Vol. IX. Schmeisser: 'Ueber das Vorkommen und die Gewinnung der nutzbaren Mineralien in der Südafrikanischen Republik.' Berlin, 1894. Kuntz: 'The Rand Conglomerates.' *Rep.* of Geolog. Soc. of South Africa, 1894. F. A. Hatch and J. A. Chalmers: 'The Gold Mines of the Rand.' London, 1895. L. de Launay: 'Les mines d'or du Transvaal.' Paris, 1896. Gives the best summary of the geological occurrence and a complete bibliography. *Ibid., The Engineering and Mining Journal*, 1897, Vol. LXIII, pp. 631-659. K. v. Kraatz: *Zeit. f. Prak. Geol.*, 1896, p. 188. G. F. Becker: 'The Witwatersrand Bankets, with notes on other gold-bearing puddingstones.' 18th *Ann. Rep.* U. S. Geol. Survey, 1896–97, part V. *Ibid., Amer. Jour. Sci.*, Mar., 1898, pp. 193-208. P. Krause: *Zeit. f. Prak. Geol.*, 1897, p. 12. G. A. F. Molengraaff: *Ann. Rep.* of the State Geologist of the S. African Rep. for 1897. Johannesburg, 1898. S. J. Truscott: 'The Witwatersrand Goldfields Banket and mining practice.' London, 1898. G. A. F. Molengraaff: 'Die Reihen folge und Correlation der geol. Form. in Südafrika.' *N. Jahrb.* f. Min., 1900, Vol. I, pp. 113–119. Also 'Géol. de la Républ. Sud-Africaine,' p. 23. L. Kessler: 'Valuation Plan of the Witwatersrand Goldfields.' London, 1902. J. H. Curle: 'Gold Mines of the World,' p. 127. T. H. Hatch and G. S. Corstorphine: 'Origin Witwatersrand Gold.' *The Engineering and Mining Journal*, Jan. 12, 1905.

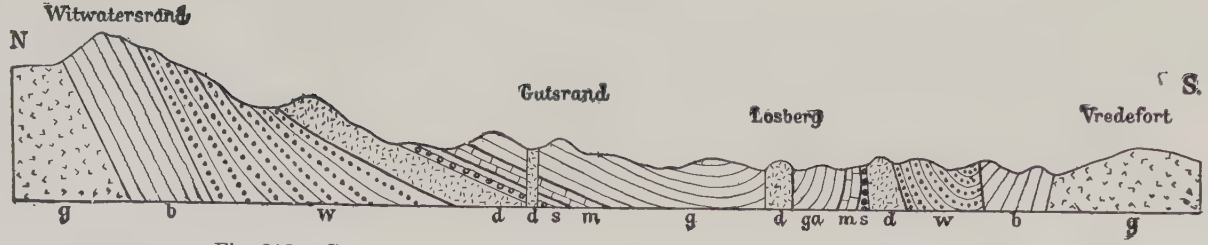


Fig. 213.—Cross-section through the Witwatersrand syncline. (Molengraaff.)

g, (ends) granite and crystalline schists; b, clay slates and quartzites of the Barberton formation; w, Witwatersrand strata with the conglomerate measures; d, diabase; s, Black measure; m, Malmani dolomite; g (center), and ga, slates and quartzites of the Gatzsrand.

Bureau at Pretoria. In contrast to this view, the Witwatersrand formation was quite recently and quite generally regarded as the lowest member of the Cape formation.

On account of their synclinal folding, the series of strata containing the gold-bearing conglomerates outcrop not only at the Rand itself, that is to say, in the vicinity of Krugersdorp, Johannesburg and Bocksburg, where their thickness is about 7,500 meters (24,600 ft.), but also farther south, in the opposite side of the syncline, at Reitzburg and near Heidelberg. The outcrop, situated far off to the southwest at Klerksdorp, belongs to the western part of the north side of the fold. The axial line of the entire syncline runs nearly in a semicircle from southwest to northeast. The north side of the syncline shows almost uniformly a very steep dip at the outcrop, which becomes more and more horizontal with increasing depth, a feature favorable for mining.

At Johannesburg, the center of the South African gold mining industry, seven groups of reefs of the gold-bearing conglomerates are known, to which must be added an eighth, the Black Reef, belonging to the Cape formation. The intervening strata consist mainly of quartzitic sandstones, more rarely also of slates. The most important is the Main reef series, embracing the North reef, Main reef, Main reef leader, Middle reef, South reef and South reef leader. It had been exploited to a distance of 80 km. (48 miles) as early as 1894.

The thickness of the reefs varies from several meters to a complete wedging out. In the Stall reef of the Du Preez mine it even attains 30 m. However, the thinner reefs are the richer.

Petrographically the conglomerates, there usually called banket reefs (banket, a baker's roll), consist of pebbles of quartz and quartzite, rarely also of silicious schist, held together by a cement of small quartz granules and iron pyrite with associated gold particles. The pebbles, mostly of the size of a hazel nut up to a hen's egg, rarely measuring 10 cm. or more, are often deformed, flattened, wonderfully distorted or splintered, evidently through secondary action. Strong pressure effects are also often shown in the cement by the splintered form of the quartz granules. The rounded pyrite granules that are occasionally found have a rolled appearance, but seem to be merely individuals whose shape is due to pressure.

The iron pyrite occurs in rather irregular distribution, as may be gathered from the photographic reproduction of a thin section, Fig. 214. Its granules often form a fairly continuous crust around the pebbles. Sometimes it is also concentrated in delicate films, running parallel to the stratification.

Fig. 214.—A piece of conglomerate from the main reef leader of the Crown Reef Gold Mining Company.

Photograph of thin section with transmitted light. (This section shows the distribution of the dark iron pyrite intergrown with gold. Enlargement 5—4.)

The gold is never found in smooth granules or flakes, as in the case of alluvial gold, but in microscopic crystals and in jagged crystalline aggregations, which often send out minute stringer-like appendages. It is mainly, perhaps exclusively, associated with zones of pressure and shearing, and is found, together with secondarily formed quartz, in the midst of a mosaic of crushed quartz fragments. The gold aggregations are mostly intimately intergrown with pyrite in such a way that the gold often encrusts a core of pyrite, or several pyrite fragments are cemented by gold. The gold is always found in the cement. In the rare cases in which it is found inside of pebbles its primary character seems very doubtful. They may represent cases in which the gold immigrated along secondary planes of fracturing. On the other hand, non-auriferous pyrite is known with certainty to occur inside the pebbles. In the cement the pyrite may occupy 3 to 5% of the total mass.

Besides pyrite and gold, this cement occasionally carries other ores, though in very small amount, namely copper pyrite, galena, zinc-blende and stibnite. Among non-metallic ingredients chlorite and a green hornblende in minute prisms are often quite abundant, also a green mica, talc, rutile and corundum.

A strange occurrence, reported by Gardner F. Williams[1], was the presence, in the stamp mill troughs that served for dressing the auriferous conglomerates of the Klerksdorp mines, of some green diamonds.

The average gold content of all the reefs of the Rand worked in 1892-3 was, according to Schmeisser, 23 grams per ton, not counting the loss in dressing; in his opinion the real content is 28-30 grams per ton. The coarser the pebbles, the richer is wont to be their cement.

Information upon the intimate connection of the gold with the pyrite may also be gleaned from the results obtained in milling the ore. According to Krause only about 64% of the gold is obtained from the amalgamation plates, another 18% through the cyanide process, while 18% remains in the tailings. This very fact points to an intimate coalescence of the gold with the pyrite, such as we found by means of the microscope. As a rule the gold is perceptible to the naked eye only in the red oxidized uppermost parts of the reefs, where the pyrite has been decomposed into red and brown hematite. At 30-40 m. (98-131 ft.) vertical depth the sulphides begin to make their appearance. Moreover, from 40 m. (131 ft.) downward, the hardness of the conglomerates increases more and more until at about 60 m. (196 ft.) primary, very firm "blue rock" becomes predominant.

The distribution of the gold in the several reefs is by no means uni-

[1] Gardner F. Williams: 'The Diamond Mines of South Africa.' New York, 1902, p. 523.

form, as appears from the following table taken from the work of L. de Launay:

VARIATION OF THE AVERAGE GOLD CONTENT AT DIFFERENT LEVELS IN THE FERREIRA MINE.

South Reef.			Main Reef Leader.		
Level.	Average thickness in cm.	Average content in gm. per ton.	Level.	Average thickness in cm.	Average content in gm. per ton.
1	60	46	1	14	97
2	40	99	2	25	35
3	28	128	3	16	171
4	43	104	4	40	34
5	33	179	5	40	54
6	84	187	6	38	65
7	63	97	7	10	107
8	84	146	8	34	44
9	52	129	9	34	45
10	48	290			
11	28	170			

The quartz sandstones alternating with the conglomerates of the Rand contain hardly any gold. An exception to this is found, however, in the rich reef of Rietfontein, which represents a sandstone very poor in pebbles, and a reef in the Buffelsdoorn mine, almost devoid of pebbles, and yet containing gold. Conversely it is true that by no means all conglomerate beds contain gold in workable quantity.

A peculiar occurrence in the conglomerates of the Klerksdorp goldfield is a layer, 0.5 cm. thick, of bituminous quartzite with a considerable content of arsenic sulphide and the exceedingly high gold value of 143.75 oz. per ton.

Finally an exceptional position is also occupied by the bed called Black reef, quite close to the base of the Cape formation. It is overlain by dolomite, is underlain by a decomposed, tourmaline-bearing eruptive rock, and consists of angular quartz fragments, held together by a cement consisting of rounded pyrite grains.

The innumerable faults traversing the conglomerates are of great importance, both from the geological and practical standpoints. Their fissures are often filled with diabase, which is very common throughout the general Rand area. These igneous dikes, sometimes as much as 30-40 m. thick, have cut off the ore in many mines.

The faults are either transverse fissures, parallel to the dip of the reefs, as for example the great fault of Bocksburg, or they are strike faults, in

which, contrary to the usual rule, the foot-wall has dropped down. (See the profile of May Consolidated mine at Johannesburg, Fig. 112.)

In consequence of overthrusts of this kind, the same reef occasionally outcrops twice, as for example the Main reef in the mine field of the Witwatersrand Consolidated Company, where the distance is 120 m. between the two parts.

No impoverishment of the reefs can be noticed in the vicinity of the diabase dikes. On the contrary, in Rose-Deep, Bonanza and other mines, astonishingly rich strikes have been made immediately adjoining such eruptive masses, the ore containing as high as 3 kilograms of gold per ton. Thus for example, exceedingly rich ores were extracted in the Ferreira mine from a portion of the reef wedged in between a decomposed eruptive dike and a fault fissure.

Secondary quartz also occurs as a result of later dynamic processes. These segregations are generally milk-white and sometimes occur in tufts, sometimes in short veins traversing a conglomerate bed. These fillings of strain fissures occasionally carry in their quartz some iron pyrite, copper pyrite, galena, blende and sometimes also gold.

The first gold was discovered in the conglomerates of the Witwatersrand by a certain Mr. Arnold, in 1884, on the Geldenhuis farm. As early as 1885, the Struben Brothers began gold mining on the conglomerate outcrops of the Gute Wilge Spruit. In 1886, the region was declared a public goldfield by the government. The town of Johannesburg quickly grew up. The discovery of coal as early as 1887 at Bocksburg facilitated the rapid development of gold mining. In 1893, as many as 70 mines were in operation, with a total output of 2,009,601 tons of conglomerate and a net return of 45,980 kilograms of gold. Shortly before the war of 1899-1900, Johannesburg numbered 70,000 inhabitants, and almost 100 companies were at work on the Rand, 55 of them with good success. The most important mines are the Robinson, which alone furnishes 1/10 of the total gold output, Langlaagte, Crown Reef, Jumpers, Simmer and Jack, Roodeport, Meyer & Charlton, May Cons., Ferreira, Geldenhuis, New Primrose, Nigel, Jubilee, Salisbury, and Worcester. In 1898, the gold production reached 109,000 kilograms.

Genesis of the Gold-bearing Conglomerates of the Witwatersrand.

The views upon the origin of these great gold deposits are still widely at variance. Four main hypotheses have been advanced:

1. Mechanical Hypothesis.

According to this hypothesis, the conglomerates are 'fossil' stream

gravels, that is to say, deposits of pebbles and sand, whose gold particles were washed into them in a purely mechanical way. This assumption is at once refuted by the microscopic condition of the gold in the conglomerates already described. The gold particles have no resemblance whatever to mechanically transported gravel gold. Neither is their distribution in the reefs such as is customary in gravels. Moreover, the hypothesis is gainsaid by the absence of gold in the interior of the quartz of the pebbles.

2. Chemical Segregation Hypothesis.

According to this *precipitation* theory, as it may be briefly called, advocated especially by Penning, DeLaunay and Stelzner, the gold was deposited as a purely chemical precipitate from sea water close to a coast, and simultaneously with the deposition of the gravels. This appears improbable (1) because in the disturbed water of the littoral zone, where gravel might be transported and deposited, such a precipitation is hardly conceivable; (2) because it ought to have taken place at least to the same extent during the deposition of the sand furnishing the quartzites; (3) because the exceedingly slight gold content of the present seas, demonstrated by Liversidge and others, does not suffice, so that recourse must be had to gold brought by mineral springs, a theory which involves the improbability that these springs should have ceased whenever sand strata were deposited, and reappeared whenever gravel was deposited.

The recent experiments of J. R. Don[1] have in fact thrown great doubt on the possibility of a precipitation of the minute gold content in sea water. Not one of the reagents occurring in nature was found by him capable of effecting a precipitation of gold from sea water.

3. Chemical Redistribution of Placer Gold.

This view was advanced by E. Cohen, endorsed by F. Posepny, and probably argued most exhaustively by G. F. Becker. The last named author compared the conglomerates with the marine gravels found at the present day on the coast of California, Oregon and Alaska, gravels whose material is said to be undoubtedly derived from eroded gold quartz veins. In these recent marine gravels, too, the gold is said to be but rarely found in the pebbles themselves; it exists in them in an evidently non-crystallized condition; its distribution, in contrast with fluviatile gravels, is said to be approximately uniform throughout the entire thickness, and finally nuggets are said to be absent from these gravels. The recrystallization of the gold, which he admits to be extensive in the Rand, he associates with the eruption of the diabases. This theory is certainly very inviting, but it does not

[1] J. R. Don: 'The Genesis of Certain Auriferous Lodes.' *Trans.* Am. Inst. Min. Eng., 1898, Vol. XXVII, pp. 564–568.

meet one weighty objection: to wit, that, if it were correct, there is all the more reason why the gold ought to be present in the beds of quartzitic sandstone, since the material of recent marine gravels is always mainly sandy.

4. Theory of the Subsequent Introduction of the Gold into the Conglomerates.

The noteworthy view called very aptly the theory of *"subsequent mineralization and impregnation"* of the conglomerates, has been especially advocated by Gardner F. Williams, J. S. Curtis, J. Kunz, K. von Kraatz, P. Krause and John Hays Hammond. It may be described as being the prevalent view among the Johannesburg mining engineers. The subsequent invasion of gold-containing solutions, assumed by this theory, is usually associated with the eruption of the diabases. The presence of numerous secondary hornblende spicules, verified by the present author, in the cement of the conglomerates, is a strong point in favor of such subsequent mineralization of the beds, formerly porous in themselves and further disrupted by dynamic processes. In this hypothesis, this pyrite is usually regarded as primary, and at the same time as a precipitant of the gold, a precipitation of gold from very dilute solutions of gold chloride and sodium chloride by pyrite having in fact been experimentally verified by Johansson and Liversidge. This theory is further borne out by the unequal distribution of the gold in the conglomerate beds and an occasional enrichment near eruptive masses. Finally, it is supported by the fact that elsewhere in the Transvaal, as in the Lydenburg district, undoubted typical sediments, to wit, the dolomites of the Malmani horizon, have been mineralized by solutions which deposited gold and quartz together with copper ores. A further argument is derived from the observation that at a horizon much higher geologically, the Black reef, there is a repetition of the gold content of a conglomerate, indicating, in a general way, a lack of constancy of horizon of deposits of this kind. At the same time, the main objection against this theory must not be passed in silence, namely, that only a few of the beds, and not all of the conglomerate beds, appear impregnated with gold, that is to say, no uniform zone of impregnation passes through all the strata of the Witwatersrand, either along fault fissures or eruptive dikes. In reply, however, attention is to be called to the original very unequal permeability of such rock strata. Thus the cement of the beds known to be poorer, such as Main reef, Elsburg, Bird and Kimberley reefs, seems, through more abundant mixture of the finest quartz sand, to have acquired a greater density than the other richer beds.

In the present state of knowledge, the fourth hypothesis seems as yet to

possess the greatest probability, although the question can by no means be regarded as decided.

2. *The Conglomerates of the Tarkwa Goldfield in West Africa.*

There has recently been a considerable production of gold from the conglomerate beds found on the Gold Coast of West Africa. The conglomerates of that region, according to S. J. Truscott[1], are found between the rivers Ancobra and Prah. They form intercalations in a sandstone composed of quartz and decomposed feldspar grains, with some magnetite and ilmenite, having a cement that is sometimes calcareous. The bed is traversed by a multitude of quartz veinlets. Besides conglomerate, the sandstone also contains intercalations of dolomite. Underlying the whole aggregate are quartz diorites, while phyllitic slates form the overlying strata. The beds form a syncline striking northeast, whose southeast limb has been studied in detail. The dip of the beds that are mined varies between 20 and 60°. Borings disclosed several masses of epidiorite.

The most important bed is the Tarkwa reef, whose thickness sometimes exceeds 1 m. The conglomerate pebbles consist of light gray, more rarely milk-white quartz, with some decomposed feldspar rock. The cement is made up of fine-grained quartz with muscovite, and occasionally of secondary quartz. Scattered through this cement there are grains of decomposed feldspar, magnetite, ilmenite and crystals of rutile, as well as gold. The gold is but rarely distinctly visible, is not accompanied by any pyrite, and has a very uneven distribution. The gold in the conglomerate, after picking out the barren pebbles, varies between 4 and 16 grams per ton, while some rich streaks have an average of 40 grams per ton. The great purity of the gold (940 to 960 fine) is remarkable, far exceeding that of the Witwatersrand gold. The richest ores occur in those portions of the bed in which the cement contains much magnetite.

Genetically, the Tarkwa occurrence may possibly not be identical with the preceding example of this class.

(f) Antimony Deposits.

1. *Antimony Deposits of Westphalia, Prussia.*

At two points in Westphalia, viz.: at the Casparizeche mine near Uentrop in the Arnsberg field and at the Paussauf mine near Nuttlar in the Brilon field, bedded antimonial deposits are known[2].

[1] S. J. Truscott: 'The Witwatersrand Goldfields,' 1902, 2d ed., pp. 487–508.

[2] L. C. Buff: 'Ueber Gangbildungen, welche lagersartige Entstehung zu haben scheinen' (Spiessglanzerze auf der Casparizeche). Karsten's *Archiv* f. Min., 1833, Vol. VI, pp. 439. A. W. Arndt: 'Ueber den Bergbau auf Spiessglanz am Silberberge bei Arnsberg.' Elberfeld, 1834.

"The occurrence in the Casparizeche, according to official data[1], is associated with the uppermost strata of the Culm, the 'Platten' limestone, which at this place forms the easternmost end of the eastward dipping Arnsberg anticline, and near by is overlain by barren sandstones. At the outcrop of the Culm strata, the top of the anticline is wanting, only the two flanks being present (northwest and southeast flanks), the southeast flank having been exposed to a distance of 1,100 meters in the search for antimony ore.

"The main anticline contains numerous smaller sharply bent and fractured folds, running in the same direction as the main fold, and the continuity of the strata is interrupted by many faults, running in all directions. The normally light-colored and firm rock is dark-colored where the ore occurs and is quite crumbly." On the southeast limb of the anticline five ore-bearing beds are known. Within these beds, but never in all at the same place, but only here and there, the ores, containing stibnite, and in the outcrop antimony ocher, form nest-like segregations 5 to 15 cm. thick. The ore forms sheets and rods extending outwardly nearly to the limiting surfaces of the strata, or occurs interspersed with the rock in small particles. Similar conditions prevail on the north flank of the anticline, except that the ores there consist mainly of antimony ocher and are less pure.

The antimony deposit of the Passauf mine near Nuttlar occurs in a series of barren sandstones forming the southwest flank of the Wiemertberg, near Vöckinghausen. There are three ore-bearing beds, the bulk of which is made up of silicious shale and black clay, with bunches of stibnite.

The presence of antimony ores at two entirely different horizons in the Carboniferous formation, together with their association with much fissured regions, renders the epigenetic nature of these deposits very probable.

The possibility of the lateral immigration of antimony ores from fissures into and along beds of shaly rocks is clearly proved by the following example:

2. *The Antimony Deposit of Brück.*

At Brück on the Ahr, in the area of which Adenau is the center, near the Eifel, antimony ores are found in the Paleozoic graywacke slates, which strike north-northeast and dip west at 45°. Within a north-south zone 24 to 32 m. in width, and exposed by workings for at least 160 m., the slate is greatly fissured and is traversed by numerous northeast veins, which dip

[1] Description of the Bergreviere Arnsberg, Brilon and Olpe, as well as those of Fürstenthümer, Waldeck and Pyrmont. Published by Kgl. Oberbergamt, Bonn, 1890, p. 158.

south at 40 to 50°, and which contain stibnite, pyrite, quartz and brown-spar. From these fissures, according to Erbreich[1], a part of the ore has penetrated between the strata and along other bedding planes of the gray-wacke schist.

3. *The Bedded Antimony Deposits of Sidi-Rgheiss in Algeria.*

The antimony deposits of Sidi-Rgheiss are situated in the southwestern part of the province of Constantine and have been mined at Sempsa and at Djebel-Hamimat. They are found in the midst of steeply dipping dark clays and limestones of the lower Neocomian, but are not confined to any definite horizon of that formation. The ore, according to Coquand[2], is in part a compact antimony oxide, milk-white to grayish in color, and with conchoidal fracture, and in part a granular crystalline variety containing druses, from which the Algerian senarmontite crystals found in so many collections have been obtained. The antimony oxide shows at times small superimposed bunches of needles of stibnite, with silky luster, some of which have been secondarily transformed into red antimony blende. The deposits form very irregular masses, parallel, however, to the stratification and without any accompanying gangue minerals.

The remarkable occurrence of isolated crystals of senarmontite in the midst of a limestone containing belemnites convinced Coquand that the ore and limestone were of simultaneous origin, and formed in sea water, to which mineral springs had contributed a considerable quantity of antimony. It seems, however, as remarked by Fuchs and DeLaunay, that the observed conditions are better explained by assuming a subsequent replacement of the limestone by the ore.

Conclusions Upon Epigenetic Ore Deposits.

The two fundamentally opposite genetic views, whose rivalry at the present day is keener than ever before in the history of economic geology, have been presented and weighed one against the other in the descriptions which we have given of numerous stratified deposits of sulphide ores of the most diverse composition and age.

[1] Erbreich: 'Geogn. Beschr. der Spiessglanz-Lagerstätte,' etc. bei dem Dorfe Brück. Karsten's *Archiv* f. Min. 1827, Vol. VI, pp. 44–53.

[2] Coquand: 'Description des mines d'antimoine oxydé exploitées dans les environs de Sidi-Rgheiss.' *Bull.* de Soc. Géol. de France, 1852, p. 342. Fuchs and De Launay: 'Traité,' Vol. II, p. 205. L. De Launay: 'Les Richesses Minérales de l'Afrique.' Paris, 1903, p. 335.

The *sedimentary* theory assumes that strata consisting of sulphide ores, sometimes of considerable thickness, have been deposited on the bottom of the ocean or sometimes of a shallow coastal sea, exactly like limestone or rock salt beds, or at any rate purely chemical precipitates of such sulphide ores were deposited by sea water in small particles associated with the normal sediments.

The other is the *infiltration* theory, according to which such deposits are due to a subsequent mineralization of ordinary sediments, at a much later geologic period, by means of an infiltration of ore solutions derived from fissures.

We believe that the reader must have gained the conviction that the conditions of structure and position actually observable argue, in most instances, rather in favor of the second hypothesis. This is particularly true of the beds of sulphide ore in crystalline schists. The lack of constancy of position in otherwise uniformly stratified ore deposits, the limitation of the beds to portions of rock strongly influenced by dislocations and traversed by eruptive rocks, the occasional occurrence of offshoots (Ueberschneidungen) at the boundary of such orebodies with the sediments, the occasional presence of vein-like spurs and stringers, and above all the microscopic relations of the ores to the other rock constituents, which often point to a later segregation of the metallic compounds—all these speak in favor of the infiltration theory.

It will contribute to the further clearing of the question, if we consider how and to what extent chemical precipitates of sulphidic ores are now forming at the bottom of lacustrine and marine waters of the present time.

The best studied phenomenon of this class is the secretion of iron pyrite and marcasite in peat bogs, swamps and under similar conditions, wherever organic substances decay under imperfect access of air, and iron-bearing solutions are present. The best known instances are the strata of iron pyrite and marcasite forming at the bottom of the so-called mineral moors of Franzensbad, especially in the great moor called Soos near that place and near Marienbad[1]. They occur mainly in the form of pseudomorphs enveloping plant stalks, but in part also in large lumps and plates. The conditions here are especially favorable to the precipitation of ore, because the numerous mineral springs rising in the moor continually introduce iron salts into the water thereof, in particular sulphate of iron, which to some extent undergoes a direct reduction to iron sulphide by the plant remains

[1] H. Loretz: 'Ueber die in den fossilen Brennstoffen vorkommenden Mineralien.' *N. Jahrb.* f. Min. 1863, p. 661. E. Palla: 'Recente Bildung von Markasit im Moore von Marienbad.' *N. Jahrb.* f. Min. 1887, Vol. II, p. 5. O. Bieber: 'Das Mineralmoor der Soos.' Marburg, 1887, p. 30. C. Ochsenius: 'Ganz junge Bildung von Schwefelkies.' *N. Jahrb.* f. Min. 1898, Vol. II, p. 232.

decaying at the bottom, while by far the greater part are precipitated as oxidic compounds.

Occasionally, the formation of sulphides of other rarer metals, though not on so large a scale, has been observed as a sequel to this kind of reduction phenomena. Thus in the lead mine of Bennerscheid, east of the Siebengebirge, according to Nöggerath and Bischof, old mine timbers were found to be coated with crusts consisting for the most part of zinc sulphide, with silicic acid, alumina, etc., water and some cadmium sulphide[1]. In true sediments, however, such phenomena are not known.

That decaying animal substances may also effect such a reduction is proved by Bakewell's observation that a mouse, lying in a bottle containing a solution of green vitriol, became coated with small crystals of iron pyrite[2]. This explains the frequent occurrence of fossils mineralized by iron pyrite or marcasite in almost all known formations, as in the case of the ammonite shells which have been more or less replaced by that ore.

An example of the recent formation of iron pyrite in sea water was reported by Forchhammer from the coast of Bornholm, where decaying fucoidal seaweed comes in contact with an iron-bearing spring water. The reaction in this case takes place indirectly[3]. The sulphates of the seaweed are reduced by the process of decay to sulphides, which, on rapid decomposition in the presence of carbonic acid, yield carbonates and hydrogen sulphide. The latter precipitates the iron as iron sulphide from the solutions brought by springs into the small bay, so that the pebbles on the sea bottom are covered with a beautiful yellow film. G. Bischof inferred from this that the crystals and granules of iron pyrite in the alum schist and in similar rocks were likewise formed by the action of decaying fucus remains on the iron-bearing sea mud.

On the bottom of some parts of the sea considerable amounts of hydrogen sulphide are developed by the reduction of the alkaline sulphates dissolved in the water, in consequence of the decomposing organic detritus, the gas occurring in large enough amount to precipitate metallic salts, especially in the depths of the Black Sea[4].

N. Andrussow describes a mud containing ferrous sulphide from the Black Sea[5], as follows:

"The mud of the deep-sea bottom is for the most part of two kinds: the black mud on the slopes (between 540 and 1,290 m.) and the dark blue mud on the level bottom of the sea.

[1] G. Bischof: *Lehrb.* d. chem. Geologie. 2d ed., 1863, Vol. I, p. 559.
[2] Fuchs: 'Die künstlich dargestellten Mineralien,' p. 55.
[3] Cited by Bischof: *Lehrb.* d. chem. Geol., 1st ed., 1863, Vol. I, pp. 926–927.
[4] J. Walther: 'Einleitung in die Geologie,' 1893–4, p. 661.
[5] N. Andrussow: 'La Mer Noire.' *Guide* des Excursions du VII. Congr. Géol. Intern., 1897, Vol. XXIX, p. 13.

"The black mud of the slopes, which is very tough and sticky, always becomes gray the moment it is exposed to the air. The discoloration is due to the presence of ferrous sulphide (FeS), which oxidizes very quickly in the air. Under the microscope the coloring matter appears partly in the form of small isolated globules, partly as an impregnation between the sand grains. The presence of such globules in the interior of diatoms is of particular interest.

"By dredging, masses of blue mud are sometimes obtained in the same region, which occasionally contains nail-shaped concretions of ferric sulphide. This mud probably lies under the black mud.

"The dark blue mud of the deep-sea bottom is less dense and encloses many diatoms, especially pelagic ones. It also contains FeS, but in less amount, concealed, it would seem, by a more or less considerable amount of $CaCO_3$, which is fine-grained and sometimes gathers into small lumps."

Although the possibility of precipitation of sulphide ores, on a small scale, both from fresh and from salt water, has to be admitted, yet there is nothing forming at the present day that presents an analogy to the formation of such vast pyrite accumulations, in part of varied mineralogic composition, as are found in increasing frequency and size the farther we delve down into the strata of the earth. We do not attach any very great importance to the insignificant sulphide formations of the present day, because we are able to find a better explanation. These remarks are suggested by observations which plainly show that in foliated rocks the ore was introduced through fissures.

We refer particularly to an example from Burgundy, noted by Bonnard (1825-28), and later described again by A. Daubrée[1].

Southeast of Avallon, on the high plains of Étaules, a granite mass is traversed by numerous veins of chalcedony, hornstone and quartz, but containing also fluorspar, barite, galena and iron pyrite, thus showing that they belong to the barytic lead formation. Above the granite is an arkose belonging to the Lias, the lowest member of the Jurassic group. Along the plane of deposition of this arkose, the solutions rising through the vein fissures have overflowed, as it were, and have completely impregnated the porous rock with their deposits. These relations are shown in Fig. 215 after Michel Lévy and Ch. Velain. The siliceous minerals form in this case either merely the cement of the arkose or solid streaks in which fluorspar, barite and galena occur, both disseminated and in a compact form, filling small stringers and druses. The shells of *Gryphaea* and other *Con-*

[1] A. Daubrée: 'Les Eaux Souterraines aux époques anciennes.' Paris, 1887. p. 126.

chylia occurring in the lowest Lias are in such cases always completely silicified.

A similar occurrence, and one in which rich and workable ore beds have been produced by lateral infiltration from vein fissures, occurs at the Enterprise mine, near Rico, Colorado.

Reference must be made here also to the interesting conditions disclosed by the Silberfennig mine in the Hohen Tauern[1]. The gold veins at that place cut the gneiss, but abut against the unconformably overlying calcareous mica-slate. Some of the overlying beds are impregnated with pyrite, galena, zinc-blende and siderite, entire layers of spathic iron occurring parallel to the stratification, while galena and blende have been worked to a less extent. The immigration of the ores from the fissures seems in this case quite certain.

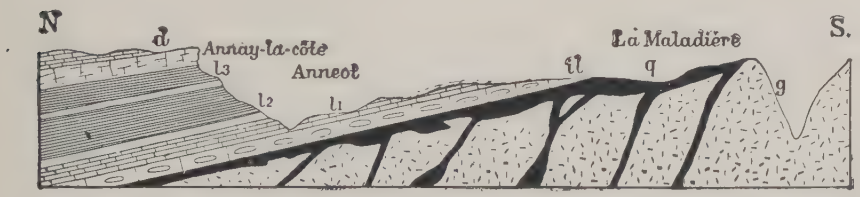


Fig. 215.—Section through the high plains of Étaules, near Avallon, France.

In this work we have repeatedly had occasion to speak of ore deposits whose dimensions and form cannot be satisfactory explained by simple infiltration of beds of suitable but originally barren rock, or through a metasomatic replacement of congenial strata, but seem to require an antecedent cavity formation. Broken Hill in particular, as well as many Norwegian pyrite deposits, would seem to need this interpretation. An attempt to show this in detail is made by Th. Kjerulf[2]. His idea of the processes at work in such cases is best and most briefly set forth by a view of his model given in Fig. 216. It shows that a folding and a subsequent overthrust may actually produce cavities intercalated parallel to the stratification, exactly similar in shape and occurrence to the ore masses of the Norwegian pyrite beds. Further investigations are needed in order to pick out all the cases in which this origin is properly to be assumed. Such examples should perhaps be more properly referred to as stratum veins, but such discrimination seems as yet impracticable.

Much as the sedimentation theory and the infiltration theory differ from

[1] 'Unters. des Bergb. in den Hohen Tauern.' Vienna, 1895, *Herausgeg.* vom k. k. Ackerbau-M., p. 77.

[2] Th. Kjerulf: 'Geologie von Norwegen.' Translation by A. Gurlt. Bonn, 1880, plate XVIII, Fig. 263.

each other in their respective explanations of the genesis of epigenetic ore deposits, they were found to agree in one point, namely, in assuming that the ores were deposited from solutions. Even the mode of precipitation of the sulphides from such solutions is in many cases conceived to be alike by the advocates of both theories, inasmuch as they point to the reducing agency of bituminous substances. In many cases it is found that the epigenetic ore deposits in question even now enclose such substances.

A sort of compromise theory was recently advanced by F. Klockmann, formerly a zealous adherent of the pure sedimentation theory. He first applies his new explanation to the pyrite beds of the Rio Tinto field. These, according to him, are "concretionary segregations within a plastic clay mud (consolidated as a slate) impregnated with the chemical elements

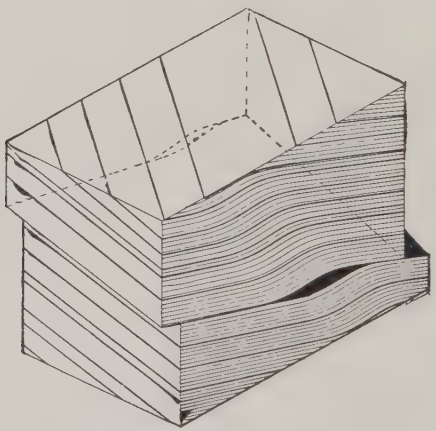


Fig. 216.—Model of slip cavities subsequently filled by ore as 'ore rods.'

of the pyrite." The preceding saturation of the mud with these elements he conceives as connected genetically with the eruptive masses of the locality (effusive according to him), which he describes as "bringers" of ore[1].

A new idea in the explanation of the genesis of certain epigenetic ore deposits has recently been advanced by E. Kohler[2], who calls attention to the importance of processes of adsorption.

By adsorption is meant the property of porous carbonaceous and colloidal substances, such as gelatinous silicic acid, as well as kaolin or clay, to retain a part of the substances dissolved by highly dilute solutions which pass through them. Thus a one per cent aqueous solution of copper-ammonium

[1] F. Klockmann: 'Ueber das Auftreten und die Entstehung der südspanischen Kieslagerstätten.' *Zeit. f. Prak. Geol.*, April, 1902.

[2] E. Kohler: 'Adsorptionsprocesse als Faktoren der Lagerstättenbildung und Lithogenesis.' *Zeit. f. Prak. Geol.*, 1903, pp. 49–59.

sulphate passed through a filter coated with kaolin loses its entire copper content as copper oxide, the filtrate consisting only of a solution of ammonium sulphide. This property of adsorption is attributed by Kohler to the clays of many epigenetic deposits, for example, that of the lead-bearing stone of Commern, the Freihung lead-bearing sandstone, etc., in explanation of the deposition of ore by metalliferous solutions seeping in from fissures. This idea is worthy of careful consideration, especially since in lodes themselves masses of clay and kaolin often prove to be richly impregnated with ore. A good analogy is also found in the kaolins of Broken Hill, so rich in horn silver, the Australian students of that deposit having years ago compared the action of those kaolins with that of a filter.

Less convincing is Kohler's attempt to explain the ore content of the copper schist by an absorption of the metallic salts supposed to have been dissolved in the Zechstein sea, by a subsiding turbidity during the process of sedimentation, a process he invokes in order to sustain the deep-rooted idea of the simultaneous origin of sediment and ore.

B. EPIGENETIC ORE STOCKS.

The name *epigenetic ore stock* was given on an earlier page, for the sake of brevity, to all the stock-shaped, pocket-shaped or tube-shaped (chimney) orebodies found in limestones or dolomites, and formed essentially by means of a metasomatic replacement of the carbonates of the original rock, by ores and accompanying non-metallic minerals. As will be shown in discussing the several examples, the process of replacement, in the formation of these deposits, was perhaps often accompanied by the filling of pre-existing cavities, leached out or dissolved out at an earlier time by solutions quite different from those that finally supplied the ore.

The epigenetic ore stocks, like ore-bearing veins, are grouped according to the predominant or most characteristic metals, while in each group the examples may be further arranged according to the age of the country rock, although this factor is genetically of but subordinate importance.

(a) Epigenetic Stocks of Iron and Manganese Ores.

1. *The Iron Ores of the District of Elbingerode in the Harz.*

At the Büchenberg, in the Gräfenhagensberg forest district, near Elbingerode, iron ore deposits have been worked for more than 500 years[1].

[1] Important publications: Hauchecorne: 'Die Eisenerze der Gegend von Elbingerode am Harz.' *Z.* f. d. B.-, H.- u. S.-W. im preuss. St., 1868, Vol. XVI, p. 199. M. Koch: 'Gliederung und Bau der Culm- und Devonablagaerungen des Hartenberg-Büchenberger Sattels.' *Jahrb.* d. preuss. geol. Landesanst., 1895, Vol. XVI, p.131.

The structural conditions are rather complicated, but have been carefully worked out and explained by M. Koch. According to him, the Paleozoic strata at the Hartenberg and Büchenberg form an anticline within which the following strata are developed, from above downward:

Graywackes	Culm.
Posidonia slates	
Adinoles, whetstones and silicious slate	
Cypridina slates	Upper Devonian.
Clymenia limestone	
Younger diabase tuff and amygdaloid	
Stringocephalus limestone	Upper Middle Devonian.
Keratophyre with intercalations of tuffs and tentaculite slates	
Older platy trap and diabase amygdaloid	

The iron ores of this region have for the most part been produced by a gradual displacement of the original calcium carbonate of the Stringocephalus limestones by iron compounds. They consist mainly of calcareous and silicious red and brown hematite and in part also of magnetic iron ore. To a subordinate extent hematite deposits, some of them workable, have also been produced from the keratophyre (orthoclase porphyry) during its decomposition, as a result of an enrichment formed by the iron, not only from the magnetite of the rock, but also from ferruginous silicates and from iron pyrite. Such ores, with still fresh keratophyre cores, outcrop, for example, on the east side of the Gräfenhagensberg open-cut. Parts of other deposits are also worked in the Bunte Wormke mine near Mandelholz and in the Oberer Stahlberg mine near Neuwerk. The ores are fine-grained to dense, clayey, silicious red hematites, with some magnetite.

The Stringocephalus ores attain a thickness of 30 m. (98 ft.) at the Büchenberg, and have been opened to a length of about 4 km. (2.4 miles) in the strike, mainly by open-cuts, which have left extensive pits (Blaue Pinge). The mines of that region comprise altogether six fields. The deposits are found to be for the most part steeply tilted, dipping as high as 50 to 70° and more north.

South of the Büchenberg lies a second iron ore deposit, which is worked by open-cut and drifts at Tönnichen. The ores occur in nearly horizontal beds forming a basin, and carry two intercalations, both of the diabase tuffs, which also forms the floor, and of the Stringocephalus limestone. The deposit is more than 1,200 m. (3,936 ft.) long. The ore, especially that of the lower divisions, contains recognizable fossils of the Stringocephalus stage.

In detail, the strata both at the Büchenberg and at Tönnichen are much disturbed by folding and overthrust, as may be learned from Koch's description.

It seems almost certain that the iron for the mineralization of the Stringocephalus limestone was furnished by the decomposition of the diabase tuffs and amygdaloids.

Quite analogous conditions exist in the iron ore deposits in the Rhenish schists at Brilon, Wetzlar, Weilburg, Dillenburg and elsewhere, which need not be further discussed here[1]. This group also includes the iron ores associated with diabases and diabasic tuffs, in the Devonian of Moravia and Silesia[2], for example at Bennison in Silesia.

2. *The Iron Ore Deposits of the Iberg, near Grund, in the Harz.*

According to F. Klockmann[3], the massive upper Devonian limestone of the Iberg and the Winterberg, near Grund, in the upper Harz, is cut up to an extraordinary degree by fractures. The long veins, which traverse the Culm graywackes and slates, show a complete change of behavior in this rock. They are resolved into a tangle of fissures and clefts, only a few of which are marked by any notable extent or uniformity in direction. The waters circulating through all these open courses produced rather extensive and very irregular or tube-shaped cavities, especially at the points where fractures intersect or unite. The cavities are filled with the residue from the leaching of the limestone, a red cave-clay, whose tenacity causes it to be sought after as material for the tamping of drill holes. Some of these cavities carry also barite, as well as calcspar and quartz, but pay-ores only occur within this Devonian limestone, along the continuation of the Prinz-Regenter and the Oberen veins. On the other hand, the Devonian limestone has in many places been replaced by iron ore, through a metasomatic replacement of the calcium carbonate by iron carbonate, the spathic iron ore being, however, now almost everywhere secondarily transformed into brown hematite. The other isomorphous carbonates mingled with the iron carbonate were in this secondary alteration segregated as calcspar, dolomite spar, manganite, psilomelan and wad. The accompanying minerals are barite, quartz, pyrite, copper pyrite, bornite, malachite and asphalt.

The limestone stock of the Iberg is at some places completely dotted with pockets and bunches of iron ore, often arranged in rows or strung along the fissures. Some of these ore stocks are 130 feet thick.

[1] W. Riemann: 'Das Vorkommen der devonischen Eisen-und Manganerze in Nassau.' *Zeit. f. Prak. Geol.*, 1894, pp. 50–57.

[2] A. Pelikan: 'Ueber die mährisch-schlesische Schalsteinformation.' *Sitzungsb.* d. k. Ak. d. W. in Wien, math.-naturw. Kl., 1898, Vol. CVII.

[3] F. Klockmann: *Berg- und Hüttenwesen* des Oberharzes. Stuttgart, 1895, pp. 62–65.

The mining industry of Iberg, formerly very active, came to a standstill about the eighties.

3. *The Iron Deposits in the Devonian Rocks of the Southern Ural, Russia.*

Extensive iron deposits, mainly brown hematite, are associated with the lower Devonian limestones of the Pervukhina district near Ust-Katavsk, in the southern Ural[1]. They outcrop on the slopes of Mounts Shuida, Irkuskan and Bulandikha, and are exploited especially near the mining town of Bakal.

The steeply upturned and elevated Devonian strata in this region, in part folded into an anticline, show the following section:

3. At the top, quartzites and sandstones, forming odd-shaped mountain crests and rocky heights. The débris blocks cover the ground far and wide.

2. Gray, yellowish-gray, greenish or reddish slates, with intercalations of dolomitic limestone, sometimes of great thickness.

1. Quartzitic and sericitic shales, black and gray dolomites and clay slates with the ore deposits.

All the strata are traversed by numerous diabase intrusions, forming dikes, sheets and sills and perhaps also genuine contemporaneous flows.

The orebodies, at some depth, consist of spathic iron-ore, which is distinctly seen to end against the dolomitic limestone, and is thus recognized as a later replacement product. In the upper workings the spathic iron ore has been transformed into brown hematite, which at present constitutes by far the greater amount of the output. These brown hematites enclose many cavities, with stalactites of brown hematite hanging down from the roof.

The deposits of Mount Irkuskan are a typical example. The lowest rock is a quartzitic slate, banded in cross fracture, with clay slate above it, capped in turn by several layers of brown hematite. All the strata are more or less upturned. The most extensive iron ore measure has been opened by means of a very large, crater-shaped open-cut. In this cut it is seen that at the top a part of the original limestone stratum has been preserved, whereas farther down it seems to be completely mineralized. Despite the cavernous structure of the hematite, the former stratification of the limestone may still be perceived in it, and one may see very clearly that the ore replaces the limestone along the strike. Of the smaller beds within the blackish-gray overlying shales, the one most distant from the

[1] Th. Tschernyschew: *Guide* 7th Cong. Geol. Inter., Vol. III, p. 31.

large deposit is of interest in that it still consists of spathic iron ore. The series of strata is terminated by a quartzite with beds of conglomerate.

The ores are roasted, alternate layers of ore and birchwood being built up into great heaps, close to the mine. Next they are sent to the iron works of Simsk, Nikolayevsk, Katav-Ivanovsk, Jurezan and Satkinsk,

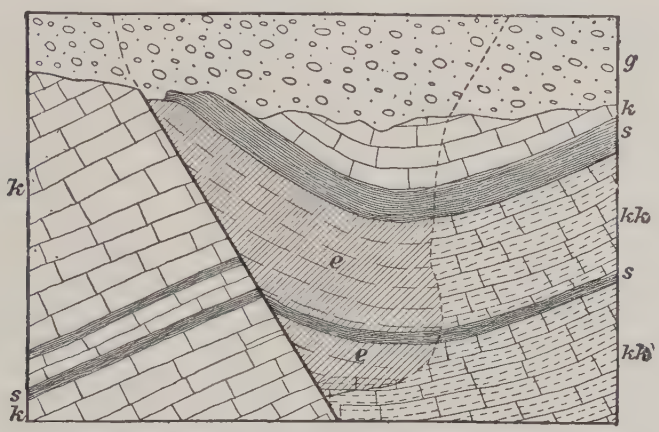


Fig. 217.—Section through the red hematite bed of Crossfield. (Kendall.)
g, boulder clay; k, limestone; kk, highly silicious limestone; s, slate; e, red hematite.

all of which own their mines. In the nineties, the Crown mines of the Bakal district produced annually more than 100,000 tons of ore, and in the other fields about the same amount. The Crown alone has on hand an amount of ore estimated at six million tons, workable by open-cut; the other fields about twenty million tons.

4. *The Red Hematite Ore Deposits in the Limestones of England*[1].

In Cumberland and in the Forest of Dean numerous red hematite deposits were found in Lower Carboniferous limestone, the deposits being very often distinctly associated with faults. From these faults, the iron-bearing solutions, which caused the limestone to be metasomatically replaced by iron ore, seem to have penetrated into the country rock. Sometimes the ore is found to contain Carboniferous brachiopods and corals, partly transformed into hematite, and pseudomorphs of hematite after calcite have also been found. These processes become especially intelligible where thin intercalations of slate in the limestone continue from the latter

[1] Important publications: J. D. Kendall: 'The Iron Ores of Great Britain.' 1893. W. W. Smyth: 'The Iron Ores of Great Britain.' *Mem.* of the Geolog. Surv. 1856, part 1. Phillips-Louis: 'Ore Deposits.' 1896, pp. 176, 247.

into the adjoining ore stocks, without undergoing flexure or interruption (Fig. 217). The deposit shows distinctly that the ore was not deposited in large open cavities, but that the calcium carbonate was dissolved molecule by molecule and replaced by ore. All these hematite deposits were probably originally spathic iron ores and were further transformed, only afterward, by atmospheric seepage water[1].

5. *The Iron Ore Deposits in the Zechstein Dolomite of the Region of Schmalkalden.*

Deposits of spathic iron ore and brown hematite found along the Stahlberg and Klinge faults near Schmalkalden, in the Thüringerwald, which are worked at the Stahlberg and on the Mommel, as well as at the Klinge, are replacements of the dolomites of the zechstein formation[2]. Water charged with carbon dioxide circulated through the faults just mentioned and i even to-day issuing from the Stahlberg fault as the Liebenstein Spring. The water exchanged its $FeCO_3$, metasomatically, for the $CaCO_3$ and $MgCO_3$ of the adjoining dolomite. The iron ores are distinguished by their high manganese content and by the absence of phosphoric acid. Besides those faults, veins of fluorspar and barite are also found.

6. *The Iron Ore Deposits of Amberg.*

The iron ores of Amberg, formerly regarded by Gümbel as Cretaceous sediments, have been demonstrated through the work of E. Kohler[3], and the earlier work of Gümbel[4], to be metasomatic formations, essentially formed by the replacement of Upper Jurassic limestones and dolomites.

The deposits, which have been worked since A. D. 930, occur, according to E. Kohler, "along a northwest fault line which has the direction and is in part a continuation of the Pfahl fault which passes through the eastern part of the Franconian Alb." The ore masses of the Amberg iron district were formed where the great fault zone is crossed by a transverse fault fissure. The deposits consist of a group of large and small bunches and lenses lying in clay and sand, and represent in the aggregate

[1] The investigation of Van Hise on the iron ores of Michigan points to a different origin for these Cumberland deposits, namely, their deposition as replacements by vadose waters in a trough formed by the fault.

[2] H. Mentzel: 'Lagerstätten der Stahlberger und Klinger Störung.' *Zeit. f. Prak. Geol.*, 1898, p. 273. Bücking: 'Gebirgsstörungen südwestlich vom Thüringer Wald.' *Jahrb.* dr. preuss. geol. Landest., 1882.

[3] E. Kohler: 'Die Amberger Erzlagerstätten.' *Geogn. Jahreshefte*, Munich, 1902, pp. 1–50. With full bibliography.

[4] v. Gümbel: *Sitzb.* d. math. phys. cl. d. k. bayr Ak. d. W. Munich, 1893, Vol. XIII, pt. 3, pp. 293–320.

a highly irregular, steeply southward-dipping stock. The ores are mainly brown hematite, in lesser part a saccharoidal spathic iron ore. Fine druses of secondary vivianite are of mineralogic interest. The entire stock of ore and clay rests upon the strongly folded and disintegrated rocks of various Jurassic formations, and, like them, is unconformably overlain by the Cretaceous rocks. The replacement of the Upper Jurassic dolomite by the spathic iron ore is rendered evident by transitions between the two.

Farther northwest are the mines of the Arzberg and at the Etzmannsberg. Here again, Dogger oolites, Malm limestones and dolomites have been replaced by an orebody, along an intersection of faults. Similarly, the ore lens of the Maximilianshütte, situated farther west, is associated with Malm limestones.

The iron ore deposits of the Luitpold mine, near Gross-Schönbrunn, and of the Leonie mine, near Auerbach, are associated with a second main fault, the Vileseck-Auerbach line. The ores here lie between the lower Dogger strata and the dolomites of the Malm, which have been dragged down to this level. Here, too, they consist in part of spathic iron ore, whose structure resembles that of the dolomite.

7. *The Iron Ore Deposits in the Lower Cretaceous at Bilbao.*

The deposits of Bilbao, near the Bay of Biscay, in Spain, are probably the largest and most important examples known of spathic iron ores of metasomatic origin.

Bilbao lies on the Nervion river, which is navigable to a distance of 14 km. (8.4 miles) above the port of Portugalete. The mines occur in a zone

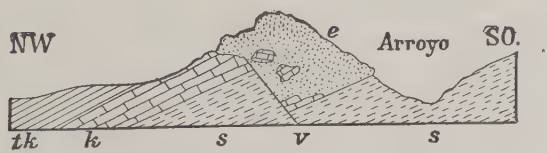


Fig. 218.—Cross-section through the Confianza mine. (De Yarza.)
th, clayey limestone; k, limestone; s, sandstone; v, faults; e, iron ore.

about 5 km. (3 miles) wide and 20 km. (12 miles) long, running west-northwest, near the southwest of the river just mentioned, and at Bilbao itself on the northeast side of the river. The most important mining points noted in succession from west to east are: Sommorostro, Galdames, Triano, Moro, Orconera, Miravilla, El Morro and Ollargan.

All the deposits, according to D. R. A. de Yarza[1], occur in the Lower Cretaceous area and are associated with thickly bedded limestones of the Urgo-Aptien stage underlain by micaceous sandstones and frequently overlain by marly limestones of the same age. The ores form very irregular bodies in the midst of the limestone, and in some cases replace it entirely, with the exception of a few as yet unmineralized blocks, as shown in the section, Fig. 218. Sometimes the ore is only found along fissures, and in fact it is visibly dependent on the faults which traverse the Cretaceous rocks, mostly raised into flat anticlines. No eruptive rocks are known in the ore field itself. A zone of ophitic rocks passes at some distance to the northeast[2].

The ores are classified into various groups:

1. Vena, a soft, efflorescent, purple-red hematite.
2. Campanil, a hard, crystalline, red hematite, often accompanied by calcspar rhombohedrons.
3. Rubio, a brown hematite with silicious admixtures.
4. Hierro espatico, spathic iron ore.

We proceed to give for each of these groups the limiting values of 5 to 6 analyses after De Yarza's summary:

	Vena.	Campanil.	Rubio.	H. espatico.
FeO	.....	.....	.....	40.32–54.19
Fe_2O_3	70.12–91.70	69.51–84.01	69.93–83.75	1.71–18.49
SiO_2	1.05–7.19	3.20–6.60	2.50–14.20	0.27–5.95
Al_2O_3	0.65–1.53	2.14–3.80	0.20–3.20	0.17–1.05
Mn_2O_3	0.70–2.24	1.90–5.80	0.78–2.45	0.80–1.18
CaO	0.13–9.27	0.40–4.60	0.50–2.23	2.10–3.70
MgO	Trace–0.46	0.54–1.25	Trace–0.94	0.15–0.69
SS	Trace–0.07	Trace–0.02	Trace–0.13	0.04–0.17
P	Trace–0.02	Trace–0.01	Trace–0.94	.....
H_2O, CO_2, etc	3.81–19.44	6.30–17.10	3.23–14.67	26.00–37.90
Fe	49.10–64.20	48.65–58.80	48.85–58.80	42.00–48.80

There can hardly be a doubt that originally all the ores of Bilbao were formed as spathic iron ore. The proverb current among the local miners, *"La caliza es la madre del mineral"* (the limestone is the mother of the ore), expresses the genetic connection between limestone and ore. On the other hand, the origin of the iron-bearing solutions is as yet uncertain.

The thickness of the orebodies is sometimes very great, as in the main deposit of Triano, where it is 100 ft. at places.

[1] D. Ramón Adán de Yarza: 'Descripción Fisica y Geológica de la provincia de Vizcaya.' Madrid, 1892. *Mem.* de la Com. del Mapa Geol. de Espagna. M. S. Czyszkowski: 'Explor. Geólog. de la région ferrifère de Bilbao-Sommorostro.' Alais, 1879.

[2] See F. D. Adams: Canadian Mining Inst., 1903. Also, E. Mackay Heriot: 'Iron Ores of Bilbao,' *The Engineering and Mining Journal*, October 3, 1903, p. 510.

The production of all the iron ore fields at Bilbao has risen from 2,800,075 tons in 1881 to 4,782,521 tons in 1901. In 1896 about a half million tons were exported to Germany alone from Bilbao[1].

8. *The Manganese Deposits of Nassau, the Wetzlar District, in Hesse and on the Hunsrück.*[2]

In the regions just named, the surface of the Middle Devonian Stringocephalus limestone, underneath its cover of soil and alluvial material, is very commonly found to be eroded by atmospheric water in a most irregular fashion. Deep gashes, basins and pipes, or flat grooves and troughs, alternate with sharp crests and jagged points or broad ridges and mounds. At the same time the limestone near the surface is often dolomitized. A manganiferous residual formation lies above the dolomite, following all those varied forms of the relief, not only filling the depressions, but also extending across the elevations. The base usually consists of an unctuous, bright yellow or reddish clay, up to 2 m. thick, as shown in the section (Fig. 219.) Lying upon this there is a manganiferous brown hematite, usually in crusts and loose sintery masses, more rarely granular, and holding nests and pockets of pure manganese ore. These porous ores are often replaced by brown-colored clays. The whole is covered by light pink clays, together with pleistocene gravels, sands and clays. The thickness of the mass of manganese ore may rise to 6 m. or in exceptional cases even to 12 m. The harder nests of pure manganese, enclosed in the manganiferous brown hematite, consist of psilomelane, manganite, pyrolusite, polianite and wad. Their interior cavities not infrequently contain kidney-shaped, botryoidal and stalactitic masses, or are lined with small crystals of man-

[1] H. Wedding: 'Die Eisenerze an der Nordküste von Spanien in den Provinzen Vizcaya und Santander.' *Verh.* d. Ver. f. Gewerbfl. Berlin, 1896, pp. 293–321. Also *Zeit. f. Prak. Geol.*, 1897, p. 254. W. Gill: 'The present position of the iron ore industries of Biscay and Santander.' *Journ.* of the Iron and Steel Inst., 1896, II, pp. 36–100.

[2] A. v. Klipstein: 'Ueber die Dolomite der Lahngegenden und das Vork. von Manganerzen.' v. Dechen's *Archiv* f. Min., Vol. XVII, 1843. C. Zerenner: 'Die Braunstein- oder Manganerz-Bergbaue in Deutschland,' etc. Freiberg, 1861. O. Hahn: 'Geogn. Beschr. des Districtes der Lindner Mark,' etc. *Z.* d. D. G. G., 1863, Vol. XV, p. 249. W. Riemann: 'Das Vorkommen (etc.) des Braunsteins im Kreise Wetzlar.' *Z.* f. d. B.-, H.- u. S.-W im preuss. St., 1862, Vol. X, pp. 2–12. Also 'Eisen- und Manganerze in Nassau.' *Zeit. f. Prak. Geol.*, 1894, pp. 50-57. A. Buchrucker: 'Das Manganerz-Vork. am Hunsrück.' *Jahrb.* d. preuss. geol. Landesanst., 1895, Vol. XVI, pp. 1–9. F. Beyschlag: 'Das Manganerz vorkommen der Lindner Mark bei Giessen in Oberhessen.' *Zeit. f. Prak. Geol.*, 1898, pp. 94–96. R. Delkeskamp: 'Schwerspatvorkommnisse in der Wetterau und in Rheinhessen und ihre Entstehung zumal in den Manganerzlagerstätten.' *Notizbl.* d. V. f. Erdk. Darmstadt, 1901, series IV, pt. 21, pp. 47–83. Same author: 'Hessische und nassauische Manganerzlagerstätten.' *Zeit. f. Prak. Geol.*, 1901, pp. 356–365. With bibliography. Bellinger: 'Bemerk über Niedertiefenbach,' etc. *Zeit. f. Prak. Geol.*, 1903, pp. 68–70.

ganite and pyrolusite. These ores sometimes also contain nodules of barite, with drusy centers. The presence of fossils, replaced by manganese ores, proves that not only have actual cavities been filled, but the substance of limestone and dolomite has been metasomatically replaced. It is assumed that the Devonian limestones originally possessed a sufficient manganese content to be concentrated, like the clayey residue and the ferric hydrate, during the long period of the superficial solution of the rock, into these manganese ores. F. Beyschlag regards the clays of the Giessen occurrence as products of the secular weathering of clay slates or other Upper Devonian rocks, and maintains an introduction of iron and manganese solutions from elsewhere by means of waters flowing over the surface of the limestone, with accompanying interchange between the limestone and the iron and manganese compounds.

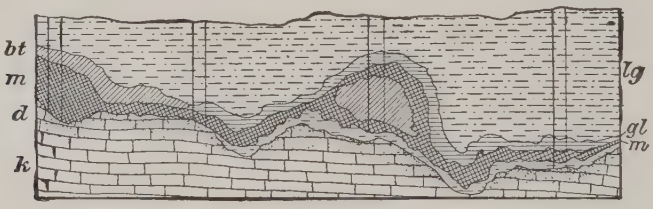


Fig. 219.—Section of the Braune Liesel mine, near Niedergirmes. (Riemann.)
k, limestone; d, dolomite; gl, yellow clay; m, manganiferous limonite; bt, brown clays; lg, clays with nodules.

The vast mass of overlying clays is regarded by Delkeskamp, too, as a younger formation, probably of Pliocene age, whose origin does not coincide with that of the manganese ores.

Formerly the hard manganese ore was separated by a wet process from the lean efflorescent ore and sold separately for the preparation of chlorine. Since the seventies, however, all the manganiferous ores are extracted and used in the iron furnaces mainly as flux for the oolitic 'minette' ores of Lorraine and Luxemburg. In 1900 the production of manganese ore of this kind from the Weilburg mining fields was 2,430 tons, from the Cons. Schlossberg mine, of the Regierungsbezirk of Wiesbaden, 3,460 tons, and for the entire mining district of Bonn, 57,954 tons.

Precisely similar manganese ore deposits occur in the zechstein dolomite at Morsberg near Vierstöck, at Erzbach, Rohrbach, Bockenrod and Waldmichelbach in the Odenwald[1]. The amount of manganous and ferrous carbonate in the dolomite, as well as the simultaneous occurrence of man-

[1] C. Chelius: 'Erl. zur geol. Karte v. Hessen.' Brensbach sheet, 1897. G. Klemm: Erbach sheet.

ganspar, besides pyrolusite, psilomelane and brown hematite, all indicate that the ores represent weathering products of the dolomite.

As an appendix, mention may also be made of the closely analogous manganese ore deposits at Monte Argentario on the south coast of Tuscany, which also rest on the dissected surface of a limestone[1].

9. *The Manganese Deposits of Las Cabesses in the French Pyrenees.*

The manganese deposits of Las Cabesses and vicinity lie in the Department de l'Ariège, between the valleys of the Salat and the Ariège. The ores are associated with variegated limestones of Upper Devonian age, called griottes, which are widely distributed on both sides of the range. According to Klockmann[2], these limestones are overlain by black slates of the Lower Culm, and underlain by Upper Devonian slates. The deposits are formed at the outcrop of manganese oxides, while at but little depth they consist of rather pure manganese carbonate with but little silicic acid and mere traces of phosphorus. From numerous analyses furnished by the owners, the above named author found the following average composition:

Mn, 40–42%; Fe, 1.5–2%; CaO, 6%; SiO_2, 6–7%; P, 0.04–0.05%.

The ores are compact and are hard to distinguish by their appearance from the surrounding variegated limestone (griotte), in which they occur as exceedingly irregular stocks and funnels. The orebody now worked at Las Cabesses consists in the upper levels of two 'chimneys,' with a cross section 50 m. long and 12 to 15 m. wide. At a greater depth the two ore columns unite into one stock. These orebodies form the hanging-wall of a steeply southward-dipping overthrust fissure, filled with black vein-clay shale (Gangthonschiefer), and are cut off below by a second strike-fault, dipping gently south. Furthermore the ore masses are cut by numerous transverse fractures. These fissures, according to Vital[3], are the channels of supply of the manganiferous solutions, which, according to that author, caused a metasomatic replacement of the limestone by manganous carbonate. F. Klockmann, on the contrary, thinks it probable that a concentration of the manganese primarily present in the former calcareous mud took place during the sedimentation of the limestone itself. This interpretation does not seem to be borne out by the form and arrangement of the orebodies, described by him in detail, and is controverted by their relations to the fissures mentioned above.

[1] A. v. Groddeck: 'Lagerstätten,' p. 258.

[2] F. Klockmann: 'Montangeologische Reiseskizzen.' *Zeit. f. Prak. Geol.*, 1900, pp. 265–275.

[3] According to a report mentioned by Klockmann.

It may be added that elsewhere in the Pyrenees manganese deposits are found, conformably intercalated between Devonian shales or at their contact with limestones, especially between the Vallée d'Aure and the Vallée d'Aran. These strata consist of manganese oxides, passing below into rhodonite and friedelite, so that they are properly referred to the occurrences described on page 109.

(b) Epigenetic Tin Ore Stocks.

1. *Tinstone in a Lower Liassic Limestone of the Campiglia, Italy.*

One of the most remarkable tinstone deposits, rediscovered only recently, but known to the inhabitants of the ancient town of Populonia, is found at the southernmost spur of the mountains of Campiglia, called Monte Valerio[1]. In a limestone assigned by B. Lotti[2] to the lower Liassic, a mass of brown hematite occurs, which in the Cento Camerelle and the Cavina mining works is found to enclose bodies of tinstone. The latter was also discovered later in a pure limestone.

A. Bergeat[3] found the tin-bearing limonite in irregular, many branched stocks in the limestone, as well as in the form of a lode in the neighboring Posidonia slate, and recognized pyrite enclosing tinstone and pseudomorphs after it, together with traces of malachite in the ore. The tinstone forms crystals of columnar habit in drusy cavities of the ore. As noted by that author, the occurrence does not belong to the typical tin deposits, but to the transition form described on page 217.

About 2½ km. (1.5 miles) from the deposit, according to B. Lotti, there is a dome of post-Liassic tourmaline granite, whose underground continuation into that region is not impossible.

At any rate this tin deposit belongs in the group of metasomatic deposits, for the tin ore has undoubtedly replaced the limestone.

2. *Tungsten Ores in Crystalline Limestone in Connecticut.*

At Long Hill, in the town of Trumbull, near Bridgeport, Connecticut, Shepard and Percival[4] long ago described a remarkable deposit of tungsten

[1] G. vom Rath: *Sitzungsber.* d. Niederrh. Ges. f. Natur- und Heilk. March 5, 1877. Also *Zeit. f. Prak. Geol.*, 1894, pp. 324–326. Fr. Blanchard: 'Sulla scoperta della cassiterite a Campiglia.' *Boll.* geol., 1876.

[2] B. Lotti: 'Sulla genesi dei giacimenti metalliferi di Campiglia Marittima.' *Boll.* del R. Comit. geol., 1900, No. 4, 1–11.

[3] A. Bergeat: 'Beiträge zur K. d. Erzlagerstätten von Campiglia Marittima.' N. J. f. M., 1901, Vol. I, pp. 135–156.

[4] E. U. Shepard and J. G. Percival: *Report* on the Geolog. Surv. of Connecticut, 1837–1842.

ore, which later on was more accurately described by A. Gurlt[1]. The tungsten ores replace crystalline limestone and have a close genetic resemblance to tin veins.

A younger metamorphic hornblende gneiss encloses a bed of crystalline limestone 10 to 15 m. thick. Both are traversed (1) by a quartz vein 1.8 m. thick, (2) by a topaz vein 1 m. thick, accompanied on both sides by a selvage of violet-colored fluorspar, quartz, blende and mica (margarodite), as well as some wolframite, (3) by a feldspar vein (albite with some beryl and blende). At the contact plane between the lower hornblende schist and the limestone, the latter, within the area of those veins, contains a stratum 1 to 1.5 m. thick, of scheelite, wolframite and wolfram ocher, with quartz as gangue, as well as with pyrite, epidote, calcite and mica. The wolframite occurs exclusively as a pseudomorph after scheelite. At first, therefore, only calcium tungstate was found.

The occurrence is now reopened (1904) and worked[2].

3. *Tungsten Ores in a Cambrian Dolomite.*

According to Irving[3], granular crystalline aggregates of wolframite have been developed near Lead and Deadwood in the Black Hills of Dakota, within the same dolomite lenses of the Cambrian sandstone that contain the gold deposits described farther on. They form large flat orebodies, containing also some quartz, barite and scheelite. Veins carrying tungsten are known in those mountains, but thus far only in the Nigger Hill and Etta Knob tin fields.

(c) Epigenetic Ore Stocks of Copper Ore.

The Copper Deposits of Bisbee, Arizona.

These deposits[4] occur in Carboniferous limestones in the southeast corner of Arizona. They lie near the Mexican boundary on the east slope of the Mule mountains. The orebodies occur in limestone on the southwest side

[1] A. Gurlt: 'On a remarkable deposit of wolfram ore in the U. S.' *Trans.* Am. Inst. Min. Eng., 1894, Vol. XXII, p. 236.

[2] W. H. Hobbs: 'Tungsten Mining at Trumbull, Conn.' *Bull.* 213, U. S. Geol. Surv., 1903, p. 98.

[3] J. D. Irving: 'Wolframite in the Black Hills of South Dakota.' *Trans.* Am. Inst. Min. Eng., 1901. Also Prof. paper No. 36, U. S. Geol. Survey, 363-9, 1904.

[4] J. Douglas: *Trans.* Am. Inst. Min. Eng., February, 1899. F. L. Ransome: 'Geology and Ore Deposits of the Bisbee Quadrangle.' Professional paper No. 21, U. S. Geol. Surv., Washington, 1904.

of a great fault, and are closely associated with an intrusive mass of granite porphyry. The orebodies form great, irregular sheets in limestone; they are generally parallel to the bedding, but only occur near the fault or porphyry. The limestone forms the fractured southern half of a synclinal basin containing sills and dikes of porphyry. The ores are mainly oxidized, consisting chiefly of cuprite, malachite and azurite, and in part native copper in the upper levels, but deeper down are found with manganese ore and brown hematite, forming bunches, pockets or vast stocks, in a clayey mass rich in iron and manganese. These ore-bearing clays either occur as very bulky and quite irregularly shaped masses in the midst of the limestone, or they rest on the limestone.

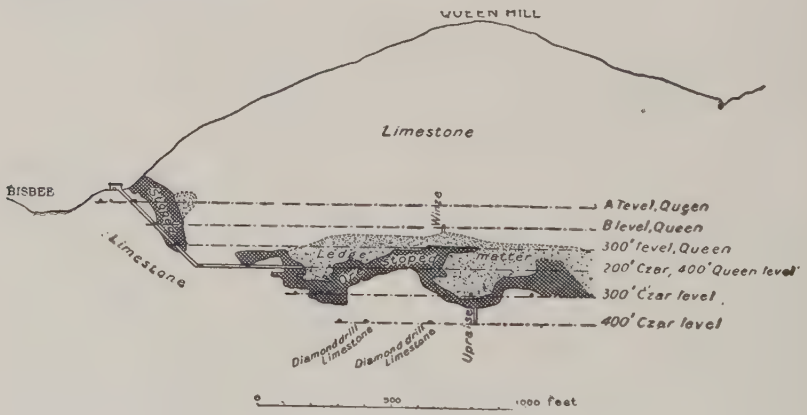


Fig. 219a.—Section of the Copper Queen mine, Bisbee, Arizona. (Douglas.)

At some points, large masses of ore show a core consisting of sulphides, particularly pyrite poor in copper, surrounded by the rich oxidic copper ore, and this by clays poor in ore. It is also stated that the surrounding limestone contains fine sprinklings of iron pyrite and copper pyrite. These sulphides seem to have been the source of the oxidic copper ores, while the clays are to be regarded as residues from leaching, but have probably acted as ore-depositing agents, as explained under adsorption.

The oxidic copper ores are also found, for that matter, on the floor of cavities on whose ceiling copper-bearing calcspar stalactites were observed[1].

A second example belonging to this class is presented by the copper ore deposit of Saint Genevieve, in Missouri.

(d) Epigenetic Stocks of Silver, Lead and Zinc Ore.

Replacement deposits of this kind, in part in connection with genuine

[1] F. L. Ransome: *Bull.* 213, U. S. Geol. Surv., 1903, p. 149.

cavity fillings, occur in calcareous rocks of very diverse ages. In the following pages we give detailed descriptions of the following districts:

1. Laurium, Greece	In crystalline schists.
2. Eureka, Nevada	In the Cambrian.
3. Monteponi, Italy	
4. Mississippi Valley, United States	In the Silurian.
5. Missouri, United States	
6. Iserlohn, Germany	In the Carboniferous.
7. Aachen, Germany	
8. Picos de Europa, Spain	
9. England	
10. Leadville, Colorado	
11. Aspen, Colorado	
12. Upper Silesia, Germany	In the Triassic.
13. Wiesloch, Germany	
14. Raibl, Austria	
15. Bleiberg, Austria	
16. Mapimi, Mexico	In the Cretaceous.
17. Santa Eulalia, Mexico	
18. Sierra Mojada, Mexico	

1. *The Ore Deposits of Laurium, Greece*[1].

The mountainous region of Laurium, in Greece, which contains numerous ore deposits, lies in the extreme southeastern part of Attica. According to R. Lepsius, the crystalline country rock consists of the Lower marble, above this the Kaesariani mica slates and the blue-gray, thinly stratified Upper marble. Finally the Cretaceous formation rests unconformably on the other rocks. The Cretaceous consists of a basal Lower Cretaceous limestone, the so-called "Iron limestone," covered by the green Athenian slates and marls (see section Fig. 220). The Lower marble, the one in which the famous marble quarries of the Pentelicos are located, outcrops at Laurium only in the deepest incisions of the valleys, but forms the main country rock in the deep mines of Camaresa. A characteristic feature of the region is the presence of numerous intrusions of gabbros, all more or less serpentinized. Associated with these there is at Plaka a small granite stock, whose tongues penetrate the sedimentary series as far upward as the Cretaceous marls. This granite is surrounded by a contact zone in which the Kaesariani mica schists are metamorphosed into an augite-epidote-garnet rock.

[1] Most important papers: A. Cordella: 'Le Laurium,' Marseilles, 1871. *Idem*: 'Mineralogisch-geologische Reiseskizzen aus Griechenland,' Liepzig, 1883. R. Nasse: 'Mittheilungen über die Geologie von Laurion und den dortigen Bergbau,' *Z.* f. d. B.-, H.- u. S.-W. im preuss. St., 1873, Vol. XXI, pp. 12-22. B. Simonet: 'Laurium,' *Bull.* de la Soc. de l'industrie minérale, St. Etienne, 1883, 2d series, Vol. XII, p. 641 *et seq.* R. Lepsius: 'Geologie von Attika,' Berlin, 1893, p. 63 *et seq.* J. J. Binder: 'Laurion: Die attischen Bergwerke im Alterthum,' Laibach, 1895. M. F.: 'Die geologischen Verhältnisse der laurischen Erzlagerstätten,' *Zeit. f. Prak. Geol.*, 1896, p. 153. Α. Κορδέλλα. 'Ο μεταλλευτικος τιλοῦτος τῆς 'Ελλάδος. 'Εν 'Αθήναις. 1902, C. v. Ernst: 'Ueber den Bergbau im Laurion.' *Jahrb.* d. k. k. Bergak., Vienna, 1902, pp. 447-501. H. F. Collins: 'The Mines of Laurium, Greece,' *The Engineering and Mining Journal*, November 10, 1904, p. 751.

Both the crystalline rock and the overlying Cretaceous strata are, according to Lepsius, "bent up in the mountain land of Laurium into an anticlinal fold, whose axis runs straight through the whole mining field from the south coast at Legrana north-northeast, across Camaresa, the Rimbari mountain range, and across the pass of Plaka as far as the northeast coast toward Daskalio-Niki; the main ore deposits and the Plaka granite stock occur in the anticline." The strata of the east flank of this anticline dip very regularly and at a low angle to the east-southeast, while the west limb has undergone disturbance. In the deep workings below Camaresa, in the Serpieri and Hilarion shafts, the strata of this west flank dip west-northwest of 50°.

Important ore deposits are found in a bed of marble, intercalated below the lower horizon of the Kaesariani schists, and wedging out westward.

According to A. Cordella, the ore deposits consist (1) of true veins, (2) of irregular, often bed-like stocks.

The veins were worked by the ancient Greeks in the Camaresa and Sinterni valleys. They occur in both the mica schist and marble, strike approximately parallel to the anticlinal axis, previously noted, and dip west at 70° to 80°. The vein filling, parts of which may still be seen, consists of argentiferous galena, pyrite and chalcopyrite, zinc-blende, fluorspar, calcspar, quartz, yellow vein clay and some secondary minerals. The veins are thin.

The main mass of the ore occurs as stock-shaped deposits along the contact between marble and schist, extending into the former in separate bodies or shoots. Three contacts are distinguished:

1.	Upper	Athenian Cretaceous slate. Lower Cretaceous limestone (iron limestone).
2	Second	Upper marble. Kaesariani mica schist.
3.	Lower	Kaesariani mica schist. Lower marble.

The marble bed of the mining district, intercalated in the lower horizon of the mica schists, also carries masses of ore along its contact.

The ore of the different contacts is not uniform. The uppermost consists mainly of manganiferous brown hematite with but very little argentiferous galena and without zinc ores. The second and third contacts consist mainly of zinc-blende and the oxidized ores formed from it, together with argentiferous galena, cerussite, oxidized copper ores, pyrite, red hematite, spathic iron ore, calcspar, quartz and at times also fluorspar. They are therefore similar to the veins in composition. The irregular contact orebodies send out stringers, and at times upright stocks, whose arms tapering

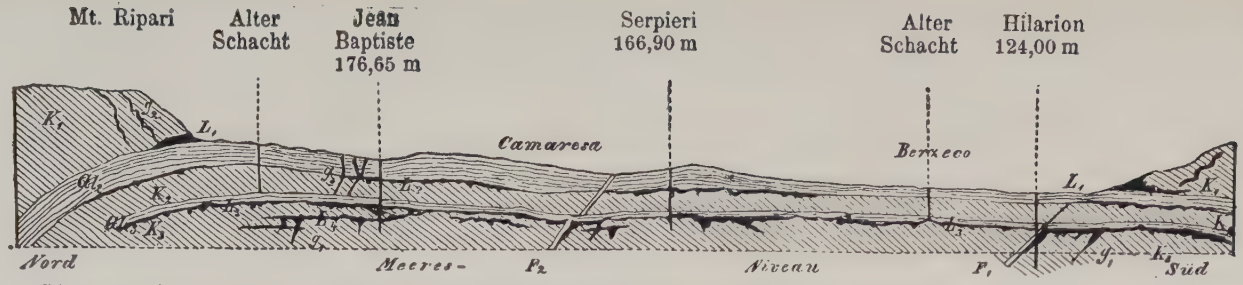


Fig. 220.—Cross-section through the most important lead and zinc deposits of Laurium, Greece. Scale 1: 15,000.

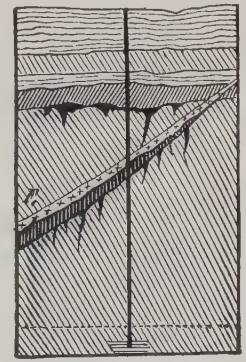


Fig. 221.—Section through the Hilarion shaft, 130 meters deep, 124 m. above the sea. Gl_2, mica schist, 18.5 m.; K_2, limestone, 9 m.; Gl_3, schist, 1.5 m.; L_3, lead ore-bed, 5 m.; m, zinc ores of floor of bed. Base of crystalline limestone, 96 m., with a felsite dike, 1 m., and a zinc vein 2.5 m. in footwall. Dotted line shows sea level; groundwater at bottom of shaft.

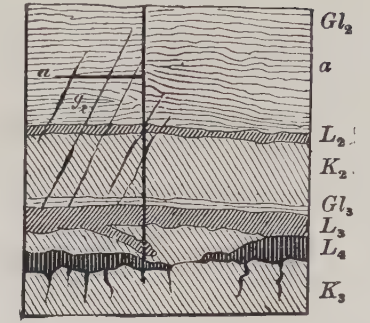


Fig. 222.—Section through the Jean Baptiste shaft, 176.6 m. above sea level, and 112 m. deep. Gl_2, mica schist, 44 m., with lead veins, g_2; a, old workings of 26 m. level; L_2, lead ore-bed, 0.5 m.; K_2, limestone, 31.6 m.; Gl_3, mica schist, 1.4 m.; L_3, third contact, lead ore-bed; L_4, zinc ore, 3.5 m.; K_3, marble.

downward, penetrate into the lower marble, as appears from the sections Fig. 221 and 222, which are copied from Cordella's work.

There can hardly be any doubt that the orebodies found in the Laurium rocks are due to an invasion by ore-depositing waters from below. As the deposits are richest near the Plaka granite mass, the genesis of the ores is, according to Lepsius and others, connected with the intrusion of that granite. The deposition of the ores is mainly the result of a metasomatic replacement of the marble, especially at points where the impervious overlying slate caused the solutions to stagnate, as a result of which ores replaced the calcium carbonate mainly along the boundary between the two rocks. The zinc sulphide was afterward altered by surface agencies into calamine, etc.

The mines worked by the ancient Athenians were mainly located in the vicinity of Ergastiria and Thoriko (Porto Mandri), where some 2,000 shafts averaging 250 feet deep have been found. Enormous accumulations of old lead slag and extensive old dumps (*ekvolades*) bear witness to the vastness of the ancient work. The ancient mining town of Thoriko existed even in Theseus' time and was fortified in the twenty-fourth year of the Peloponnesian war. According to a legend, the Laurium ores were known as early as the heroic age. According to this myth the gold was discovered by Helis, a son of Ozeans, the silver by Erichthonius, a son of Vulcan. According to Cordella, the ancients produced in the Laurium district in 300 years 2,100,084 tons of crude lead with a silver content of 22,500,000 lb. troy. In recent times the slag and dumps have been re-treated, and, besides the lead ores, the zinc ores, neglected by the Athenians, are also mined. In 1898, Laurium produced 30,650 tons of cadmia ore.

2. *The Silver-Lead Ore Deposits of Eureka, in Nevada.*

The ore deposits of Eureka[1], Nevada, and some other so-called "chamber mines" of America, such as Richmond in Nevada, Emma, Flagstaff and Kessler Cave in Utah, are irregular bodies or stocks of silver-lead ore in limestone. This type of deposit was for some time a prominent topic of discussion, because the deposits were the first accurately described examples in the United States of such irregular ore masses in easily soluble rocks. The deposits also played for a long time a prominent part in mining jurisprudence because they could not be classified under any of the categories

[1] Important papers: R. W. Raymond: 'The Eureka-Richmond case,' *Trans.* Am. Inst. Min. Eng., 1877, Vol. VI. p. 371. J. S. Newberry: 'The Origin and Classification of Ore Deposits,' School of Mines *Quarterly*, March, 1880. New York. J. S. Curtis: 'Silver-Lead Ore Deposits of Eureka,' *Monog.* VII, U. S. Geolog. Survey, 1884. A. Hague: 'Geology of the Eureka District,' *Monog.* XX, 1892.

provided in the mining laws, being neither lodes nor beds proper, and hence gave rise to many legal contests. Their geologic genesis also led to controversies, which have been of great benefit to science. Newberry regarded them as examples of genuine cavity fillings, the cavities, according to him, having been leached out by atmospheric water charged with carbon dioxide, while the filling with ore was accomplished by rising solutions. He based this view largely on the fact that the limestone of the walls of the ore-bearing chambers showed no impregnation with ore, and on the further fact that empty cavities still occurred in these districts. Later on, however, the view advocated by J. S. Curtis gained acceptance. According to him the ore was deposited by metasomatic replacement, not by cavity filling, and it was deposited by uprising solutions. The empty cavities have been shown to be due to subsequent alteration by descending surface waters.

All of these investigations were carried on in the region about Eureka, Nevada. The country rock there consists of 30,000 feet of Paleozoic strata of varied character and different ages; quartzites, limestones and slates of the Cambrian; limestones and quartzites of the Silurian; limestones and slates of the Devonian; quartzites, limestones and conglomerates of the Carboniferous. The ore deposits occur in Cambrian limestone, which has been crushed and shattered in a broad fault zone which was a channel for ore-bearing solutions. The ore formed well defined but irregular stock-shaped or tube-shaped bodies, the largest of which was followed to a distance of 400 m. (1,312 ft.) The primary ore was a rich argentiferous galena, oxidized in the upper portions to cerussite and anglesite, as well as horn-silver ores. The ores held a slight amount of gold.

3. *The Lead and Zinc Ore Deposits of Monteponi*[1].

In the Iglesias district in the mountainous southwest part of the island of Sardinia, the Silurian limestone contains extensive deposits of zinciferous galena ores and their oxidation products, that were formerly worked by the Carthagenians and the Romans. The Monteponi mine, near Iglesias, is the most important of the numerous mines. The ores occur in great columns or ore shoots over 100 m. (328 ft.) in height, 60 of which are worked. They mostly occur at the contact of clayey limestone with dolomites.

[1] Most important publications: G. Zoppi: 'Descrizione geologico-mineraria dell' Iglesiente.' Sardegna, 1888. Marx: 'Geogn. u. bergm. Mittheilungen über den Bergbaubezirk von Iglesias auf Sardinien.' Z. f. d. B.-, H.- u. S.-W. i. preuss, St. 40, 1892, pp. 263-278. Fuchs and de Launay: 'Traité des Gîtes Minéraux et Métallifères,' Vol. II, 1893, pp. 387-411. 'Carta Geologico-Mineraria dell Iglesiente,' Rome, 1888. Also, 'Carta Geol.-Miner. del Sarrabus,' Rome, 1889.

Two groups may be distinguished: a southern consisting of chimneys of galena ore, and a northern, consisting mainly of oxidized zinc ores.

The galena orebodies also contain some blende and pyrite. Calcite and dolomite spar sometimes associated with quartz form the mostly gray and breccia-like gangue (as at Livello Sella and Scavo Genieguas), also with white, foliated barite (as at Albusini). A zone of yellow ochrous clay is usually found between the ore masses and the limestone. On the contrary, where the galena directly adjoins the limestone, druses are encountered, with magnificent crystals of cerussite, anglesite and phosgenite. Cerussite is often seen with angular remnants of undecomposed galena.

In the immediate vicinity of the stocks of oxidized or cadmia ores the limestone has been altered to a fine-grained, crystalline, gray or yellowish, oftentimes foliated dolomite. The cadmia consists mainly of smithsonite colored yellowish or reddish by iron oxide, often in reniform-botryoid, fine-layered forms, black-brown on the surface, with a varnished appearance. Dolomite breccias are also found, cemented by smithsonite. Alongside of these occurs hydrosilicate of zinc (calamine), in cavernous masses, whose cavities are studded with colorless transparent crystals. Mention must also be made of the occurrence in this cadmia zone of cavities containing brown-yellow or brick-red crusts and efflorescent fillings. Fissures are also found, filled from above, with a breccia of schist and lignite fragments cemented by calcite (as in the Dislocazione Monsignore, Livello Mare).

The only eruptive rock known is a diabase dike 40 m. thick, on the road to Genieguas. At some distance from that point vein-like deposits are known, occurring in part in the granite, such as the lode series of Montevecchio, close to the contact of the Silurian slates with the granite at the high plateau of Arbus, carrying pyritous-blendic lead ore.

4. *The Zinc and Lead Deposits of the Mississippi Valley.*

The lead and zinc deposits of the Mississippi Valley are of exceedingly great economic and scientific interest, and have been carefully studied and described by various scientific observers[1]. The rocks are limestones of

[1] Important literature: J. D. Whitney: 'The Metallic Wealth of the U. S.,' 1854, pp. 403-417. 'On the occurrence of bones and teeth in the lead-bearing crevices,' Amer. Assoc. Adv. Sc., 1859. *Rep.* of the Geolog. Survey of Iowa, 1855-'57. 'Geology of Iowa,' 1858, Vol. I, part 1, pp. 286-295, 422-471. *Rep.* of a Geol. Survey of the Upper Mississippi Lead Region, Albany, 1862. A. Schmidt: 'Forms and Origin of the Lead and Zinc Dep. of Southwest Missouri,' *Trans.* St. Louis Acad. of Sc., Vol. III, p. 246. 'Die Blei- und Zinkerzlagerst. von Südwest-Missouri,' Heidelberg, 1876. A. Winslow: 'Lead and Zinc Dep. of Missouri,' *Trans.* Am. Inst. Min. Eng., Vol. XXIV, pp. 634-931. 'Lead and Zinc Dep.,' Missouri Geol. Survey, 1894, Vol. VII, p. 645. T. C. Chamberlin: 'Wisconsin Geol. Survey,' 1882, Vol. IV, pp. 451-482. W. P. Blake: 'Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Am. Inst. Min. Eng., 1894, Vol. XXII, pp. 629-632. 'Wisconsin Lead and

Silurian age over most of the region, but a part are Lower Carboniferous beds. For the present purpose they will be treated as a unit.

The deposits occur in the following districts: (1) The Upper Mississippi Valley, including southwestern Wisconsin, eastern Iowa and northwestern Illinois; (2) central Missouri; (3) the Missouri-Kansas area; (4) southeast Missouri; (5) northern Arkansas; (6) southern Illinois and Kentucky; (7) southern Arkansas.

Of these regions, (2) and (3) belong within the area of the Ozark arch, (5) to the Ouachita Mountains, separated from the preceding by the Arkansas Valley. Within the confines of these two anticlinal swells, the ore-bearing strata are gently inclined; elsewhere their dip is still less. No eruptive masses occur anywhere.

In the *Upper Mississippi Valley* the ores are confined to the Silurian, which is here classified as follows from above downward:

Cincinnati shale, 200 ft.

Galena limestone, 450 ft.

Oil-bearing shale, 2 ft. to 3 ft.

Trenton limestone, 40 ft. to 100 ft. (contains layers of shale, especially at the base).

Greenish-blue clay, 1 to 2 ft.

St. Peter's sandstone, 50 to 150 ft.

Lower Magnesian limestone, 100 to 250 ft.

Potsdam sandstone, 700 to 800 ft.

Precambrian.

The ores are found partly in 'gash veins' or vertical clefts (Fig. 224); partly in enlarged joints between strata, the so-called 'flats,' and as fillings of quite irregular rents (Fig. 223), finally also as impregnations of certain beds. They are always associated with zones of fracture. They are especially frequent in the flat synclinal depressions of the terrane, in the synclines of the folds striking east and west. The main strike of the fissures

Zinc Dep.' *Bull.* Geol. Soc. Am., Vol. V, 1894, p. 28. W. P. Jenney: 'The Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Am. Inst. Min. Eng., 1893, Vol. XXII, pp. 171, 621. F. Posepny: 'Genesis der Erzlagerst.,' Freiberg, 1893, p. 157. S. F. Emmons: 'Fluorspar deposits of Southern Illinois,' *Trans.* Am. Inst. Min. Eng., 1893, Vol. XXI, pp. 31-51. J. D. Robertson: 'Missouri Lead and Zinc Dep.' Am. Geol., 1895, p. 235. A. G. Leonard: 'Lead and Zinc Dep. of Iowa,' Iowa Geol. Surv., 1897. J. F. Kemp: 'Ore Deposits of the U. S. and Canada,' 1900, p. 240 (gives literature). J. C. Branner: 'The Zinc and Lead Region of North Arkansas,' *Ann. Rep.* of the Geol. Surv. of Arkansas, 1900, Vol. V. S. Calvin and H. F. Bain, 'Geol. of Dubuque County,' *Ann. Rep.* of the Iowa Geol. Surv., 1900, Vol. X. W. E. Burk: 'The Fluorspar Mines of Western Kentucky and Southern Illinois,' 'The Mineral Industry,' 1901, Vol. IX, pp. 293-295. C. R. Van Hise and H. F. Bain: 'Lead and Zinc Dep. of the Miss. Valley,' *Trans.* Inst. Min. Eng., London, 1902, pp. 1-60. *Idem:* 'Lead and Zinc Deposits of the Ozark Region,' 22d *Ann. Rep.* U. S. Geol. Survey, part II, 1902, pp. 31-225. G. I. Adams: 'Zinc and Lead Deposits of Northern Arkansas,' U. S. Geol. Survey, 1904. Prof. paper No. 24.

also follows this strike. The ore is found mainly in the Galena limestone. This, as well as the Trenton limestone, is very rich in organic matter.

Above ground-water level, the ores consist mainly of galena and smithsonite with calcite as a gangue. At a lower level, zinc-blende and marcasite occur, galena is rare, and pyrite and copper pyrite are subordinate accessories. Still farther down, the marcasite gradually displaces the other ores. In genetic succession, in the upper levels, galena is always the youngest ore, for its crystals coat the druses. The deposition of galena took place in geologically very recent time, and in this case it was due to descending solutions. In fact, fissures have been found that widened into chimneys

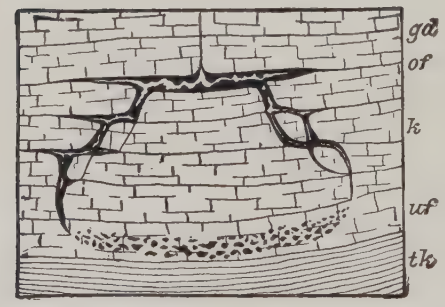


Fig. 223.—Ideal section of a Wisconsin lead deposit. (Chamberlin.)

gd, Galena dolomite; tk, Trenton limestone; of, upper flat; uf, lower flat; k, ore-bearing fissure.

Fig. 224. — Enlarged fissure filled by galena. (Chamberlin.)

containing stalactites of galena pendant from the roof, and in fissures close to the outcrop teeth and bones of Pleistocene mammals were found that were cemented by coarsely crystalline galena.

The *Missouri-Kansas area* is not only the best known but the most important and includes the important mining towns of Joplin, Missouri, and Galena, Kansas. This region lies on the west slope of the Ozark arch. Over this wide extent of country the ores are confined to certain areas, separated by barren zones.

The ores of this field occur in the Cherokee, Mississippian (Boone or Keokuk) limestone of Lower Carboniferous age, containing beds of chert; above this, when not removed by denudation, are the sandstones and shales

of the Upper Carboniferous coal measures. The ore-bearing formation is everywhere underlain by the Eureka-Kinderhook shales (Devono-Carboniferous), impervious to water. Below these follows the Devonian, Silurian and Cambrian. The orebodies are confined to zones of faulting and folding.

The ores consist mainly of galena and blende, with less amounts of oxidized zinc ores and very little marcasite, pyrite and chalcopyrite. Dolomite is the predominant gangue, though a good deal of calcite, quartz and barite is also found at times. The Joplin district alone produced in 1902 262,545 tons of zinc ore and 31,615 tons of lead ore. The total production of the Missouri-Kansas district to 1899 amounts to 2,176,700 tons of zinc ores and 631,200 tons of lead ores. Above the ground-water level the ores are limited to galena, calamine and various secondary minerals in a red clay.

The limestone in the mineral district has a crystalline texture and is so rich in bitumen in some mines that the dressing of the ores is interfered with. Near the orebodies, the normal limestone is always dolomitized. Perhaps the chert beds have also been formed by a secondary alteration of the limestone, which in that case, however, preceded the secretion of ore, for chert breccias cemented by ore are common. The form of the orebodies is similar to those of the Upper Mississippi Valley.

Conditions in the other districts are similar except that in the *Illinois-Kentucky region* the galena and blende veins found in the Lower Carboniferous limestone carry very much fluorspar in their upper parts. They are in fact mined for that mineral (as in Eagle mine, near Salem, Kentucky). At a greater depth the fluorspar is replaced by calcite. It is also to be noted that in the south Arkansas district the lead and zinc ores occur together with silver, gold and antimony ores in true fissure veins with quartzose gangue.

Concerning the genesis of all these deposits, the most diverse opinions have been advanced. Whitney, Chamberlain and Winslow explain them by assuming that the metals were primary constituents of the limestones and have been leached out by lateral secretion and redeposited by means of the reducing organic material in the rocks. The main support of this opinion lies in numerous analyses by Robertson, who demonstrated minute quantities of zinc and lead in the most diverse Silurian and Carboniferous limestones. Percival, Jenney and Blake, on the contrary, regard the ores as deposits from ascending thermal waters, rising from unknown depths. That the real deposition of ore below ground-water level took place, however, from uprising currents, is also affirmed by Van Hise and Bain. These authors, however, regard the currents not as thermal springs, but as artesian water, of atmospheric origin. From catchment areas, situated at a higher level,

it is supposed to have first seeped down, following a porous stratum confined above and below by impervious shales, and passing through the dolomitic limestones of the Silurian, to have leached out the minute amount of metal held by them. Finally reaching the fault fissures of the zone of dislocation, the water is assumed to have risen and redeposited its load in the more bituminous beds. After removal of the upper shale by erosion, a second concentration was produced by descending currents forming the deposits now mined. (See page 378.)

To the present writer, the presence of barytes and fluorite, in fact the entire mineral assemblage of the deposits, so closely resembling that of genuine silver-lead veins of hydrothermal origin, indicates that the hydrothermal theory is the correct one, especially since it will hardly be proved that the zinc and lead contents of the limestones were not themselves introduced by subsequent infiltration.

5. *The Zinc Deposits of Iserlohn, Prussia.*

At Iserlohn in Westphalia, according to L. Hoffmann[1], a series of zinc deposits were found in the Middle Devonian Stringocephalus limestone or 'Massenkalk,' being confined to the horizon immediately above the underlying Lenne shales. The deposits lie in a zone 12 km. (7.2 miles) long, extending from Lethmathe across Iserlohn as far as Deilinghofen. Fifteen separate deposits are known. Their upper boundary against the overlying limestone is generally very irregular. In some cases the masses of ore are stock-like, the thickness of the orebody exceeding the extension along the strike. These orebodies are steeply inclined, parallel to the stratification of the Devonian. The so-called "First Fissure," for example, is only 3 m. in extent along the strike of the strata, but is 25 m. in thickness. Barren limestone strata divide it into several beds, which here and there run together. The lowest of these beds rests directly on the Lenne shales, which dip north about 35°.

The ores consist of calamine, smithsonite, zinc-blende, pyrite, some galena and a limonite gossan. Fragments of unmineralized limestone are found in the midst of the orebodies. They are usually rounded, and up to several meters in diameter, occurring frequently near the boundary of the deposit. The blende is frequently developed in the form of shell blende, at times having a reniform-botryoid surface, and here

[1] Trainer: 'Das Vorkommen des Galmeis im devonischen Kalkstein bei Iserlohn,' *Verh.* d. naturh. Ver. d. preuss. Rheinl. 1860, Vol. XVII, p. 261. Eichhorn: 'Die Zinkerzlagerstätten bei Iserlohn,' *Z.* f. B.-, H.- u. S.-W. im preuss. St. 1888, Vol. XXXVI, pp. 142-149. L. Hoffmann: 'Das Zinkerzvorkommen von Iserlohn,' *Zeit. f. Prak. Geol.*, 1896, pp. 45-53.

and there coated with zinespar rhombohedrons. Thus the origin of the deposits is due partly to the replacement of the limestone, partly to the filling of cavities previously leached out. Almost all the orebodies of this locality, for that matter, extend to but a moderate depth, rapidly wedging out. The greatest depth disclosed by mining in Fissure I is only 205 m. (672 ft.)

In 1894 the Iserlohn mines produced 8,669 tons of cadmia, 4,185 tons of blende and 77 tons of galena, which figures at the same time illustrate the ratio of the quantities of these ores. Here and there pyrite has been extracted (64 tons in 1894).

Closely similar deposits occurring in the Devonian limestone of Bergisch-Gladbach have been described by von Huene[1].

6. *The Ore Deposits Near Aachen*[2] *(Aix-la-Chapelle), Prussia.*

The ore deposits in the vicinity of Aachen, 44 miles west-southwest of Cologne, do not all belong in this group, since true veins occur, as well as irregular replacements. The deposits are, however, discussed as a whole, since they are evidently related.

The geologic map of the Aachen mining district (Fig. 225) shows Devonian and Carboniferous limestones outcropping in parallel northeast-southwest belts. The beds are steeply tilted, folded and faulted by numerous dislocations. Nearly undisturbed Senonian shales cover the older rocks where not removed by erosion. Volcanic rocks are entirely absent. Detailed studies of the district show that the same horizons are repeated as a result of folding, the folds near the Belgian frontier being overturned and at Walhorn Hittfeld and Herbesthal Fossay showing overthrusts. This series of anticlinal folds and intervening syncline is cut across by a number of faults at right angles to the strike of the strata. The most noticeable is the great fault called Münstergewand, which is so important a feature in the neighboring Inde coal basin.

The ore deposits are closely connected with these transverse faults, as is at once seen from the map. Two types of deposits prevail: (1) mineral

[1] v. Huene: 'Das Vork. von Galmei, Blende, Bleierz,' etc., bei Bergisch-Gladbach' *Z.* d. D. G. G., 1852, Vol. IV, p. 571.

[2] M. Braun: 'Ueber die Galmeilagerstätte des Altenberges im Zusammenhang mit den Erzlagerstätten des Altenberger Grubenfeldes und der Umgegend,' *Z.* d. D. G. G., 1857, Vol. IX, pp. 354-370. Holzapfel und Siedamgrotzky: 'Berg. und Hüttenm. Excursionskarte in die Umgegend von Aachen,' 1886. H. v. Dechen: 'Orographisch-geognostische Uebersicht von Aachen,' 1866. W. Schiffmann: 'Die geogn. Verh. und die Erzlagerstätten der Grube Diepenlinchen bei Stolberg,' (Rheinl.) *Z.* f. d. B.-, H.- u. S.-W. im preuss., St. 1888, Vol. XXXVI, pp. 83-122. C. Dantz: 'Der Kohlenkalk in der Umgebung von Aachen,' *Z.* d. D. G. G., 1893, Vol. XLV, pp. 594-683.

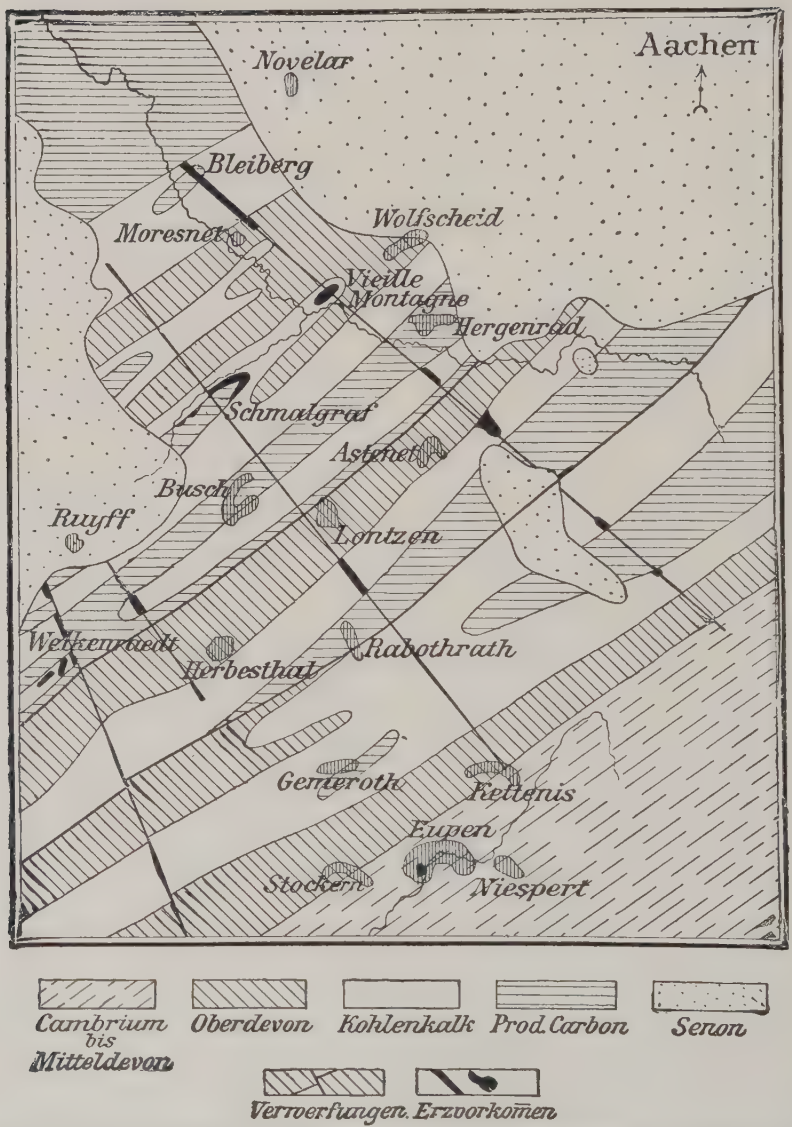


Fig. 225.—Geological sketch map of the mining district southwest of Aachen. (Dantz.) Scale 1: 120,000.

1, Cambrian to Middle Devonian; 2, Upper Devonian; 3, Carboniferous; 4, Coal measures; 5, Senonian; 6, faults; 7, orebodies.

veins; (2) replacements along bedding planes and contacts (pockets, chambers, etc.).

1. The veins all belong to the group of cross faults. In the slates (Upper Devonian) and Coal Measure rocks the fault fractures are very narrow and often scarcely recognizable. They open into broad, large and important veins in the limestones, owing to replacement and solution of the soluble rock by circulating water. These replacements consist of galena and blende with calcite, altered near the outcrop into oxidized ores. The most important lead and zinc veins are those of the Breiniger Berg, near Stolberg, the main vein of this locality passing finally into the great fault (Münstergewand) already mentioned. The ores of these veins show concentric crusts and shells, exactly like those of the irregular deposits near by.

2. The replacement deposits along bedding planes between limestone and shale show a great diversity of form and character.

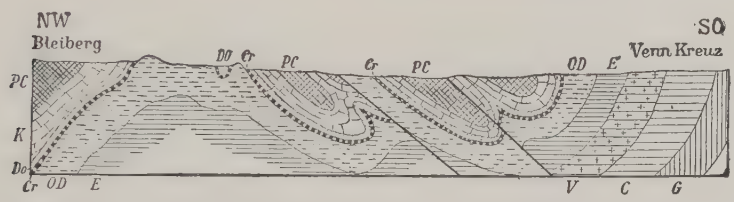


Fig. 226.—Section across the mining district between Bleiberg and Vennkreuz. IC, productive coal measures; K, limestone; Do, dolomite; Cr, crinoid limestone; OD, Upper Devonian; E, Eifel limestone (Middle Devonian); V, Vichter beds; C, Coblentz beds; G, Gedinnien. (V, C, and G are Lower Devonian.)

Thus the type found in the Diepenlinchen mine near Stolberg has the form of a greatly enlarged vein. This form grades into thick and rounded orebodies called stockworks, that lie in the Carboniferous limestone along the parting between the limestone and shale. Some of these deposits are of very large size. The largest is the 'Brennessel-Stockwork.' This deposit is said by W. Schiffmann to be merely a vein-like mass on the 34-fathom (204 ft.) level, but it increases in size in depth until at the 72-fathom (432 ft.) level it attains a maximum length of 90 m. (295 ft.) and a greatest breadth of 40 m. (131 ft.). There is no sharp boundary between the ore and the enclosing Carboniferous limestone; the ore fades away gradually into the latter. At a few points only does it end sharply against beds of solid limestone. Toward the south the orebody has vein-like spurs, and contains several unmineralized limestone pillars within its mass. The ore of the upper levels consists of calamine, galena, cerussite and some pyrite. The oxidized zinc ore passes into blende below

the 49-fathom (294 ft.) level, while the cerussite continues to the 72-fathom level. In the middle of the deposit the ore forms shelly masses in limestone or sandy dolomite, but near the border of the orebody the ore occurs disseminated through it. Calcspar also occurs in fissures and druses. On the 80-fathom level there are no oxidized ores.

In the Heinrich-Stockwerk of the same mine, exactly contrary structural conditions prevail. The orebody is seen to contract from above downward into a series of lode-like occurrences.

But even where the variously shaped and often very irregular stocks and pockets of the Aachen ores do not pass directly into true lodes, as they do here, they almost always, as shown by M. Braun, lie along the lines of intersection of the above mentioned fault fissures with the boundaries between the calcareous and the non-calcareous members of the rock. A glance at the illustration shows this for all the more important deposits of that locality. The orebodies lie at the parting between Upper Devonian and Carboniferous limestone, according to C. Dantz, as seen in the Eschenbroich, Fossey, Altenberg mines (oxidized zinc ores), and those of Poppelsberg and Welkenraedt (blende and galena). Deposits also occur between the Carboniferous limestone and the Coal Measures, as may be seen in the Eschenbroich mine (galena and blende), the Schmalgraf mine (shellblende and galena), Henriette, near Eich (brown hematite), and some cadmia (zinc) stocks of Welkenraedt.

The most famous of all these deposits is that of Altenberg (Vieille Montagne) or Kelmisberg, on the neutral territory of Moresnet, which was exhausted as early as 1844. The cubic contents of this ore stock is estimated by M. Braun at 340,000 cubic meters. According to the same author, it yielded in 500 years about one million tons of cadmia, being worked by open-cut. This vast deposit consisted almost exclusively of cadmia, in which only scattered kidneys and stringers of red clay occurred. It was formed of an intimate mixture of zinc spar and hydrosilicate of zinc, enclosing here and there larger and smaller nodules of willemite. Calamine predominated. In the upper workings druses and large cavities often occurred, with crystals of smithsonite, calamine, iron-zinc spar (capnite), zinc-bearing calcspar, more rarely of quartz. The country rock was for the most part dolomitized Carboniferous limestone, forming a syncline wedged in between Devonian slates.

Besides the stock-shaped and chamber deposits, there are also bed impregnations, usually along a definite strata, and showing an evident genetic connection with the other deposits. A bed of Carboniferous clay slate is impregnated with lead ore and blende for a distance of 2 km. to 2.3 km., according to M. Braun.

In 1898 the district just described (Düren mining district) produced 12,849 tons of blende and 5,830 tons of cadmia, the latter from the Altenberg mines of Schmalgraf, Eschenbroich, Fossey and Mützhagen. At the same time 1,303 tons of lead ore were produced, mainly in the Diepenlinchen mine.

Deposits quite similar to those mentioned are also found in Belgium, near Corphalie, Flône, Engis, and de la Mallune, near Liege, as well as in bedlike deposits near Philippeville. The extent of these occurrences may be gathered from the fact that Belgium in 1897 produced about 11,000 tons of zinc ore.

7. *The Oxidized Zinc Deposits of Picos de Europa, Spain.*

Deposits of "cadmia" similar to those of Aachen occur in Carboniferous limestones of the eastern half of the Picos de Europa in the districts of Andara and Aliva, in northern Spain[1]. Fine stalactitic masses of white, dense cadmia are extracted from cave-like enlargements of the deposits of that locality, and the ores are still forming, as shown by crusts on old tools. Here, too, the calamine stocks are associated with zones of fissuring and are probably a secondary alteration product of blende, as is proved by nodules of undecomposed blende found in them. An unusual feature is the accessory occurrence of cinnabar in these deposits.

8. *Lead Deposits in the Carboniferous Limestone, England.*

An extensive district of lead deposits occurs in the area of Carboniferous limestone rocks of Derbyshire[2]. The Carboniferous series, aggregating about 450 m. (1,476 ft.) thick, consists of the following subdivisions:

9. Millstone-grit (barren sandstone) overlying.
8. Shales of the Carboniferous limestone.
7. Limestone with thin layers of shale, 45 m. (147 ft.).
6. Bed of melaphyre (toadstone).
5. Dolomitic limestone with cavities, 45 m. (147 ft.).
4. Toadstone.
3. Limestone with layers of shale, 64 m. (210 ft.).
2. Toadstone.
1. Limestone with layers of shale, over 76 m. (249 ft.).

[1] W. Köhler: 'Die Steinkohlenformation in Nord-Spanien,' *Berg. u. Hütten Zeit.*, 1877, p. 217.

[2] B. v. Cotta: 'Erzlagerstätten,' 1861, Vol. II, pp. 494-498. Note older works of Brochant de Villiers, Dufrénoy, E. de Beaumont and De la Bêche.

The three layers of trap rock (toadstone) intercalated in the Carboniferous limestones are intrusive sills, in part of very considerable horizontal extent. The slightly inclined strata are traversed by genuine lead veins (rakes, rake-veins), which, however, almost without exception are ore-bearing only within the limestones, while in the millstone-grit and in the toadstone they grow barren and sometimes are difficult to trace at all. They are true fault fissures with slickensides and mutual displacements of moderate throw. Most of them strike east-northeast, being parallel to one another. Their filling sometimes shows a regular symmetric arrangement, with crusts of galena, fluorspar, calcspar and barite, more rarely also of quartz, pyrites and blende. Besides this, however, the limestone contains flat layers (flats) or tubular lodes (pipe-veins), that is to say, irregular ore tubes along the intersections of the veins with the joints between the strata. It was the latter fact that caused the ore deposits to be introduced in the present category. Finally, the ores are also found scattered over the cross fractures of the limestone beds (skrins). The district is a classic one in English geology, owing to the writings of De la Bêche.

Similar conditions prevail in the lead fields in the Carboniferous limestone rocks of the extreme north of England, in Northumberland, Durham, Cumberland and Westmoreland, though in these districts vein mining predominates far more over the mining of irregular deposits than is the case in Derbyshire. The most important mines lie at Alston Moore (Cumberland), East and West Allendale (Northumberland), Weardale on upper Wear river and Teesdale (Yorkshire and Westmoreland). The general section differs from that of the Derbyshire district in showing but one intrusive bed of melaphyre, the so-called Whin Sill, intercalated in the Carboniferous limestone. The lead veins have been divided into groups according to their strike: "rake veins" or "right-running veins," striking approximately east and west, "cross veins," striking north and south, and the narrow "quarter-point veins" with intermediate strike. Another peculiar feature is the occurrence of "flats," that is to say, flat, stock-like masses or sheets of ore lying parallel to the stratification. These ore masses are often connected with the veins by means of side fissures ("leaders"). The ore and gangue minerals consist of pyrite, sphalerite, galena, quartz, calcspar, fluorspar and barite. The galena is argentiferous. In 1894, according to H. Louis, the production was as follows:

	Lead ore.	Zinc ore.
Northumberland	1,042 tons.	10 tons
Durham	9,214 "	—
Cumberland	1,750 "	7,228 "
Westmoreland	1,461 "	—

9. *The Silver-Lead Deposits of Leadville, Colorado*[1].

Leadville, Colorado, lies in an upland valley of the Rocky Mountains, traversed by the main tributary of the Arkansas river. This longitudinal valley is bounded on the west by the Sawatch range; on the east by the Mosquito range, on whose foothills the town is built. The Mosquito range consists of old crystalline rocks and intensely folded and much faulted Paleozoic strata, with intrusive sheets of porphyry intruded in Cretaceous time between the beds and cutting across them. The mines lie east of Leadville on Fryer, Carbonate and Iron hills. In the town itself a deep shaft was recently sunk, which reached the ore horizon. The orebodies mostly occur within Carboniferous limestone, directly underlying porphy-

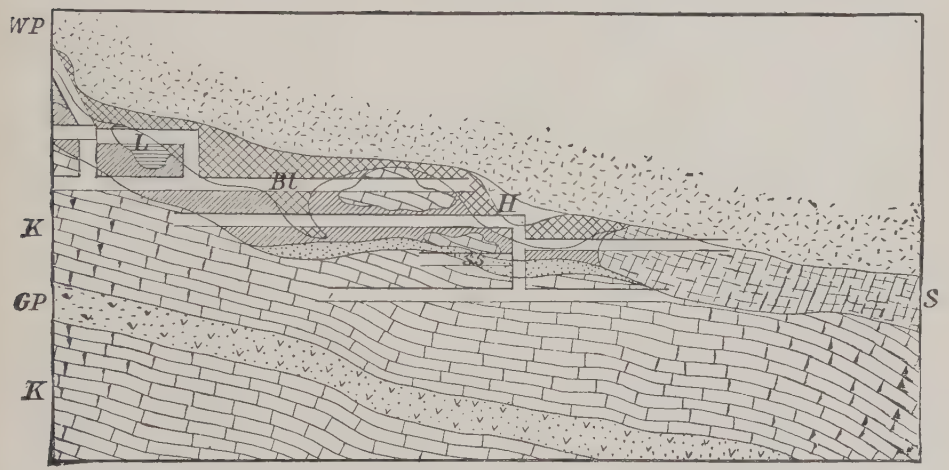


Fig. 227.—Section through the White Cap Orebody of Leadville. (Blow.)
WP, white porphyry; K, limestone; GP. sulphide ore; ss, sandy sulphide ores; Bl, oxidized lead ores; L, clay; H, cavities.

ritic intrusive masses. The few exceptions to this rule, namely, ore-beds within the porphyry, are to all appearance nothing but mineralized or replaced inclusions of the limestone in the eruptive masses. The structural conditions are well illustrated in the section, Fig. 227. The form of the deposits is that of irregular chambers or 'stocks,' in general running parallel to the stratification of the limestone, it is true, but in many cases also

[1] S. F. Emmons: 'Geology and Mining Industry of Leadville,' *Monogr.* XII, U. S. Geol. Survey, 1886. C. H. Rolker: 'The Leadville Ore Deposits,' *Trans.* Amer. Inst. Min. Eng., 1885, Vol. XIV, p. 273. F. T. Freeland: 'The Sulphide Deposits of South Iron Hill,' *Idem*, p. 183. Carl Henrich: 'Origin of the Leadville Deposits,' *The Engineering and Mining Journal*, Dec., 1879, p. 470. Also, May, 1888, p. 43. A. A. Blow: Trans. Am. Inst. Min. Eng., 1889, Vol. XVIII, p. 145. J. F. Kemp: 'Ore Deposits,' 3d edition, 1900, pp. 262-265.

cutting across the limestone beds or enclosing isolated non-mineralized patches of limestone. Sometimes these stocks are so elongated in shape that they have been termed 'pipes.'

The primary ores are sulphides, mainly argentiferous galena, zinc-blende and pyrite, with subordinate amounts of chalcopyrite, etc. The place was first famous for its rich oxidized ores, alteration products of the sulphides, which formed the great orebodies worked for many years. These ores consist of an earthy mixture of carbonates of lead and hornsilver in a clayey or silicious manganiferous brown hematite. The oxidized ores are more or less auriferous. In 1891-1892, in several mines on Breece Hill, situated about two miles east of the town, orebodies were found in the porphyry in which the value of the gold far exceeds that of the silver.

The real nature of these deposits, as a product of replacement, was recognized in the early history of the camp by S. F. Emmons, whose monograph on the district has become almost a text-book for mining geologists. He considered that the ore-bearing solutions derived their metallic contents from the eruptive rocks in the vicinity, and that the main channels of circulation were the contacts of limestone with overlying bodies of porphyry, from which they ate down into the body of the limestone along joints and cracks. Blow, writing later of the sulphide ore of Iron Hill, where it is arranged in longitudinal shoots along fissures in the limestone, thought that the solutions came up directly through these fissures and spread out along the under surface of the porphyry sheets. This view has since been generally accepted as more probable by geologic writers. Emmons had considered the possibility of such an origin, provided the fissures could be found through which the solutions ascended, but claimed that as yet none had been detected. The importance of the eruptive masses lies rather in this, that they dammed back the solutions, causing them to stagnate in the fissures and joints of the adjacent limestone, and to deposit their burden of metallic sulphides by metasomatic replacement.

The silver-lead ore deposits of Leadville were discovered in 1874. The greatest production was in 1880, but the mines are still important producers of gold, silver-lead and recently of zinc ore.

Conditions analogous to those of Leadville also obtain in the silver-lead deposits of Lake Valley[1] in New Mexico, which are stocks and pipes in a Carboniferous limestone at the contact with porphyritic intrusive masses. Lake Valley has yielded many rare minerals, such as vanadinite. The deposits of the Elkhorn mine, Montana, are also of a kindred nature, as shown farther on.

[1] E. Clark: 'The Silver Mines of Lake Valley.' *Trans.* Am. Inst. Min. Eng., Vol. XXIV, pp. 138-167, 1895.

10. *The Silver-Lead Ore Deposits of Aspen, Colorado.*

A recently published monograph by J. E. Spurr[1] has drawn attention to the interesting deposits of Aspen. This town lies on the west side of the continental divide, in the valley of Roaring Fork, close to the boundary between the crystalline schists and the Paleozoic rocks. The strata of the Cambrian, Silurian, Carboniferous and of the Mesozoic formations were here compressed in Cretaceous time into an overfold. The folding was accompanied by overthrust faulting and vertical fault fissures. Where two of these parallel overthrust planes, bringing Leadville limestone under the Weber slates (both formations being Carboniferous), are intersected by a vertical fault, masses of crushed limestone have been replaced by ore. The unaltered ore consists of argentiferous galena with a lesser amount of zinc-blende and still lesser quantities of pyrite, chalcopyrite, bornite, tetrahedrite, tennantite and in the Smuggler mine polybasite and native silver. The gangues are quartz, dolomite spar, brown spar and barite. The altered ore of secondary origin consists of earthy carbonates and sulphates, especially cerussite and anglesite, together with red and brown hematite.

The gradual replacement of limestone or dolomite by ore is well illustrated in the Aspen district by fossils found in the midst of the ore masses. Such fossils are found not only in the midst of the primary sulphide ores, but also in the masses of silver, probably of secondary origin, where some of the fossils have succeeded in retaining their form. Spurr shows that the ore-forming solutions dolomitized the limestone, with shrinkage of volume.

11. *Ore Deposits in Triassic (Muschelkalk) Limestones of Upper Silesia*[2].

The Muschelkalk[3] of southeastern Silesia forms a flat ridge between one and two miles wide and over ten miles long, extending from Krappitz, on the Oder, as far as Olkusz, in Poland. The beds dip very gently north, while the strike, as far as Siewierz, is east-west, but beyond the Russian boundary turns southeast. A deep gap extending across the middle of the ridge, north of Peiskretscham, divides it into an eastern and a western

[1] J. E. Spurr: 'Geology of the Aspen Mining District, Colorado,' with Atlas, *Monogr.* XXXI, U. S. Geol. Survey, 1898.

[2] Important publications: R. v. Carnall: 'Ueber Eisensteinlagerstätten im Muschelkalk Oberschlesiens,' *Z.* d. D. G. G., 1850, Vol. II, p. 177. v. Krug: 'Ueber die Erzlagerstätten des oberschlesischen Muschelkalkes,' p. 206. H. Eck: 'Ueber die Formation des bunten Sandsteins und des Muschelkalkes in Oberschlesien,' 1865. F. Römer: 'Geologie von Oberschlesien,' 1870. Cappel: 'Ueber die Erzführung der oberschles. Trias nördl. von Tarnowitz,' *Z.* f. d. B.-, H.- u. S.-W. im preuss. St., 1887, Vol. XXXV, p. 99. R. Althaus: 'Die Erzformation des Muschelkalkes in Oberschlesien,' *Jahrb.* d. k. preuss. geol. Landesanst, 1891, Vol. XII. G. Gürich: 'Ueber die Entstehungsw. schles. Erzlagerst.,' *Jahresber.* d. Schl. G. f. vaterl. Cultur. 1902.

[3] Triassic marine limestones above the Bunter and beneath the Keuper formations.

half. Several lateral ridges branch off, one at Tarnowitz running in a southerly direction to beyond Gleiwitz, its eastern prolongation consisting of synclinal troughs of Muschelkalk, with intervening anticlines of Coal Measure rocks. The most important of these synclines are those of Tarno-

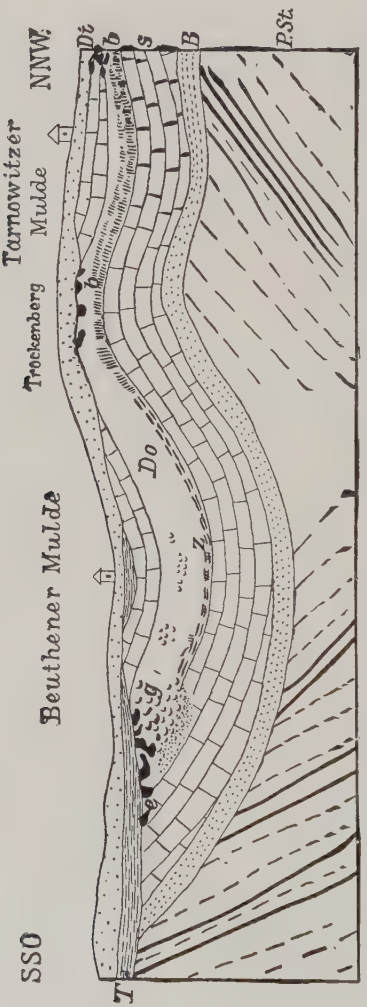


Fig. 228.—Diagrammatic section across the Tarnowitz and Beuthen basins. (Gürich.)
P St, productive Coal Measures; B, Bunter sandstone; S, Sohlen limestones (Chorzower bed); Do, dolomite; T, Tertiary; Di, alluvium; b, galena deposits; z, zinc-blende orebodies; g, cadmia bed; e, limonite deposit.

witz and Beuthen, of which a diagrammatic cross section is here given, after Gürich (Fig. 228).

In Upper Silesia (and Poland), as in the rest of Germany, the Muschelkalk forms three divisions, named by Eck:

3. Upper division: Rybna limestone, about 15 m.
2. Middle division: Non-fossiliferous, marly dolomites, about 20 m.
1. Lower division: (a) Cavernous limestone..... } about 200 m.
   (b) Chorzow strata..... }
   (c) Spirifer Mentzeli strata..... }

The lead and zinc ores occur only in the lower division. This lowest division is further subdivided by Eck into the following horizons, from above downward:

5. Himmelwitz dolomite.
4. Mikultschütz strata.
3. Encrinite or Terebratella strata.
2. Gorasdze strata.
1. Blue (basal) limestone.

The "cavernous" limestone, the "Chorzow" strata and the basal Blue limestone of the above series of strata are uniformly developed in the eastern and western parts of the plateau. The basal limestone is a dense, clayey limestone, usually of blue-gray color. The Chorzow strata are mostly thinly stratified, either dense or partly crystalline limestones or marly limestone; the Cavernous limestones are non-fossiliferous, crystalline limestones containing numerous drusy cavities.

The three upper divisions of the Spirifer Mentzeli strata differ markedly in character in the two parts of the plateau just mentioned. West of the "gap" they are pure limestones, to the east of it dolomites. As the ores occur only in the *dolomite* this eastern section alone is of economic importance. The ore-bearing dolomite when fresh is a hard, crystalline-granular rock, traversed by a network of fine fissures. Carbonaceous clays are frequently intercalated in the lower beds and almost always occur between the dolomite and the basal limestone. Because they contain pyrite, they are called 'vitriol clays.' The Himmelwitz dolomite with numerous remains of *Nullipora annulata* overlies it.

F. Beyschlag[1] regards the dolomites of Upper Silesia not as normal representatives of definite horizons of the Muschelkalk, but merely as altered limestones, formed along water-bearing fault fissures. The same water that dolomitized the limestone also supplied the ores.

In the deepest parts of the synclines the ores consist essentially of sulphides: zinc-blende, galena and marcasite, the galena predominating in the Tarnowitz syncline, the zinc-blende in the Beuthen syncline. Nearer the outcrop the sulphide is replaced by earthy zinc carbonate and silicate; where galena is present, it shows corroded forms and in cavities is

[1] F. Beyschlag: 'Vortrag über die Erzlagerstätten Oberschlesiens,' *Deutsche Geol. Ges.*, Feb. 5, 1902.

studded with cerussite crystals. Marcasite, the constant associate of the blende, is altered to hematite.

On ascending the flanks of the synclines, the dolomite disappears, and unconsolidated deposits of the marine Miocene make their appearance. Hematite and 'cadmia' occur, however, in pockets in fissures and depressions of the 'basal' or floor limestone. The zinc ores often show pseudomorphs after dolomite (the red calamine) underlain by the white calamine, a replacement of the basal limestone, showing that the mechanical processes of the Miocene sea were accompanied by metasomatic alterations. The deposits, as a whole, form two superimposed more or less continuous sheet-like masses, the upper being less regular than the lower.

Deposits of *lead* ores alone are developed in the Tarnowitz syncline. The upper part consists of a layer of soft ore, a stratum of iron ocher with irregular plates, lumps and grains of galena in the ocher. The "hard ore layer" lies below and is separated from the basal (floor) limestone only by a thin dolomite bed. It consists of a layer of galena about an inch thick, or as stringers, scattered grains and plates in the compact dolomite. Galena is accompanied by marcasite, cerussite, pyromorphite, etc. The galena carries 0.026-0.033% of silver.

Deposits of *zinc-blende* are found on the north flank of the Beuthen syncline, changing to red calamine, as the outcrop of the horizon is approached and finally changing to white calamine near the croppings.

The blende deposit, in the Cäcile and Neue Helene mines, is rarely more than 2 m. thick, while in the fields of the Blei-Scharley mines it attains a thickness of as high as 12 m. The blende, which is in part a 'shell blende' or occurs in stalactitic forms, is accompanied by galena and marcasite. The galena, however, contains only about 1/10 of the silver content of the lead ore deposits proper (*i. e.*, deposits of lead only, not mixed ores).

The upper calamine deposit has been extensively worked, especially in the Neue Viktoria, Paul Richard, Neuhof and Rudolf mines. In these workings it is about 1 m. thick, but the thickness increases southward to 10 m. It commonly contains 0.1-0.113% of argentiferous galena. Where the two layers of calamine unite at the outcrop, the combined thickness is sometimes 20 m. Thus they have been worked in the Scharley, Wilhelmine and other mines. Underlying them, the white zinc ore was often seen extending in deep fissures and cavities in the basal limestone. Compare the section through the Judith and Scharley mines in Fig. 229. There is much similarity between this and other deposits of white zinc ore found over a great part of the area underlain by older Muschelkalk. They, too, occur in part in fissure-like cavities, or lie in trough-shaped

depressions in the limestone, as for example in the Matthias mine. Alongside of these, however, sheeted white cadmia deposits have been observed.

The *iron ore* deposits consist mainly of brown hematite, the most important deposits being found on the edges of the dolomite synclines, as at

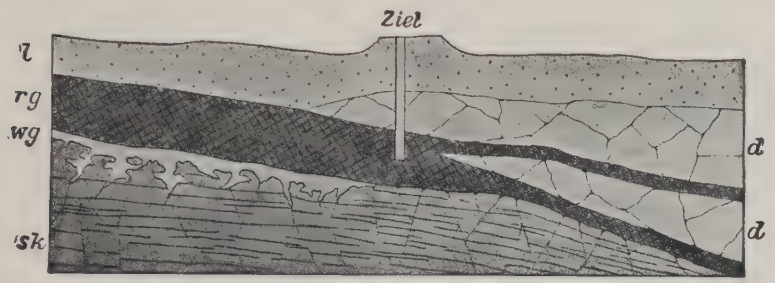


Fig. 229.—Section through the Judith and Scharley mines. (F. Römer.)
l, clay; d, dolomite; sk, basal limestone; wg, white cadmia; rg, red cadmia.

Buchatz and those north of Bobrek and south of Beuthen. The earthy brown hematite often contains some zinc carbonate, lead sulphide and white lead ore. It is banded, but forms irregular, pockety beds of varying thickness, sometimes as high as 20 m. A second mode of occurrence is in fissures and cavities of the basal limestone and of the Chorzow limestone. The brown hematite of these latter deposits often carries calamine ores. It is developed as 'Glaskopf' (radial-fibrous and concentric-shelled, as in limonite and fibrous red hematite) or in stalactites, and is sometimes distinguished by a high manganese content. As an example of the occurrence of the iron ore we give, in Fig. 230, after Römer, a section through the Bally-Castle mine.

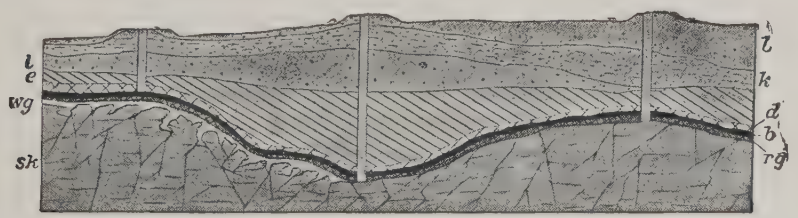


Fig. 230.—Section through the Bally-Castle mine. (F. Römer.)
l, clay; k, Krusawka; e, iron ore; d, dolomite; b, lead ore; rg, red cadmia; wg, white cadmia; sk, basal limestone.

The mining history of upper Silesia extends back to the 13th century. At that time the argentiferous lead ores in the upper-bearing horizon of the Beuthen syncline were worked, while zinc mining began only in the 16th century.

In 1898, the total output of lead in the mining district of Breslau was 40,402 tons, distributed thus: Neue Helene mine, 12,676 tons; Jenny-Otto mine, 5,043 tons; Cäcile, 4,642 tons, and Blei-Scharley, 4,406 tons. The total output of zinc ore in that year was 522,839 tons, of which 219,536 tons or 41.99% were oxidized ore and 303,303 tons or 58.01% blende. The above-named mines, together with the Samuelsglück, are the most important. Upper Silesia contributed almost 2/3 of the total zinc production of Germany.

12. *The Zinc Deposits of Wiesloch near Heidelberg, Baden.*

The Wiesloch zinc deposits are in North Baden about 12 km. (7 miles) south of Heidelberg. The deposits are in strong contrast to those of Upper Silesia, just described, being, according to Schmidt[1], largely due to cavity filling, though accompanied by extensive replacement as well.

The ores occur in fossiliferous marine limestones (Muschelkalk) that overlie red sandstones. This limestone consists of three divisions, the upper or true Muschelkalk contains no workable zinc deposits, the middle is a gypsiferous and salt-bearing series; the lower limestone (Wellinkalk) contains the valuable deposits in its lowest formation, the Trochite limestone.

The deposits are now of no economic importance, but their great scientific interest warrants a detailed description. Zinc mines exist at two points north and northeast of the town. The ore-bearing bed of the limestone is 3 to 6 m. (10 to 20 ft.) thick, resting on marls and limestones and overlaid by three thin (0.15 m.) limestone layers (Blättchen), replaced here and there by calamine ores.

Of the five deposits existing at Wiesloch, whose form may in general be described as that of recumbent stocks with north-south longitudinal extension, the three western ones whose ores are oxidized form the Hesselfeld, while the two others, situated east of the Nussloch fault fissure (which in addition to cadmia also contain blende), compose the Baierthal field. The largest of these deposits is 1,968 feet (600 m.) in length and 984 feet (300 m.) in breadth. However, none of the deposits are compact orebodies, but consist mainly of limestone with numerous pockets, connected by ore-filled clefts and joints between strata. The ore deposits occur arranged in lines parallel to the stratification of the limestone, the bunches often coalescing into large masses. These larger masses always occur along the joints between the strata and occasionally jump from a higher to a lower stratum, along a fissure.

[1] A. Schmidt: 'Die Zinkerzlagerstätten von Wiesloch' (Baden). Heidelberg, 1883. Gives a bibliography.

Besides the calamine ores, with occasional masses of blende, red clays and an argillaceous silicious iron ore also take part in the composition of these ore masses. The richest and hardest calamine ores are mostly reddish, rarely gray in color, and always lie at the lowest horizon.

Numerous vertical fissures occur connected with the pockets and trains of ore nodules. In rare cases, the fissures contain only clay, more frequently iron and zinc ore, or they are filled with zinciferous limonite, red and brown cadmia (smithsonite ores).

The Blendestock deposit of the Baierthal zinc district, unlike all the deposits mentioned, consists in its southern part almost solely of iron pyrite and zinc-blende, the latter in the form of shelly blende, that is to say, with thin intercalations of galena and pyrite. It is to be noted that these blende-carrying patches of ore lie mostly below ground-water level.

As the blende is everywhere readily detached from the country rock, and as its stratiform structure points to uninterrupted formation, and moreover as it occurs in great stalactites, up to 15 cm. thick, and not rarely 30-40 cm. long, A. Schmidt has no doubt that it and the other sulphuretted ores fill pre-existing cavities. That the solutions in question came from above, as assumed by him, may not be generally admitted. According to the same author the masses of cadmia gained the space they now occupy mainly by a metasomatic replacement of the limestone. This is actually proved by the fossils transformed into cadmia, for example by the completely mineralized specimens, yet recognizable in all details, of *Terebratula vulgaris, Lima striata, Enerinus, Lilliformis,* etc. The entire cadmia (exclusively smithsonite) of the Wiesloch deposits is, according to Schmidt, secondary and formed by the decomposition of blende, with diverse migrations of the resulting solutions.

The Wiesloch mining industry is very ancient. It was carried on as early as the time of Charlemagne, when the silver-lead ores were worked. Zinc mining began in 1846. The Hesselfield now produces about 200 tons of calamine ore per year.

13. *The Lead and Zinc Deposits of Raibl in Carinthia, Austria.*

These deposits occur in an east-west alpine range of Triassic limestone. Raibl lies southwest of Villach and south of the Gail valley in the basin of the Seebach (Schlitz), whose sources are on Italian territory. The heights all around the place rise up to about 1900 m. The ore deposits occur in limestones and dolomites beneath a series of fossiliferous shales, carrying fish remains of Middle Triassic age.[1]

[1] E. Kayser: 'Geol. Formationskunde,' 1902, 2d ed., p. 319.

According to F. Posepny[1] and the official monograph on Raibl,[2] by W. Göbl, the limestones are cut by fault fissures, usually mere partings between polished walls in close contact. These north-south fissures show a displacement of as much as 60 m. (196 ft.), the faults being characterized by brightly polished slickensides, and by partial bending over of the adjoining ends of the strata. They are recognizable even at the

Fig. 231.—Ore deposit of the Josefi-Blatt, near Nordfeldort, Aloisi adit. (Posepny.)
d, dolomite; z, sphalerite; b, galena; sp, magnesian spar.

surface, as the deeply cut erosion gorges or "Klamme" have followed their course.

These fault seams do not carry any ore, while the readily soluble dolomite and limestone contain orebodies, especially along the bedding planes between the fossiliferous slates and the overlying strata.

There are two separate fields in the district. In the first, deposits of zinc-blende and galena occur in dolomite rocks with oxidized ores in the

[1] F. Posepny: 'Die Blei- und Galmei-Erzlagerstätten von Raibl in Kärnthen,' *Jahrb.* d. k. k. geol. Reichsanst., 1873, Vol. XXIII, pp. 317-420.

[2] 'Geol.-Bergm.-Karten mit Profilen von Raibl nebst Bildern von den Blei- und Zink-Lagerstätten in Raibl,' Vienna, 1903, with full bibliography.

uppermost horizon. In the second, calamine without blende and but little galena occurs in limestone.

The sulphide deposits of the first area, according to F. Posepny, distinctly betray their character as cavity fillings. Their dimensions and

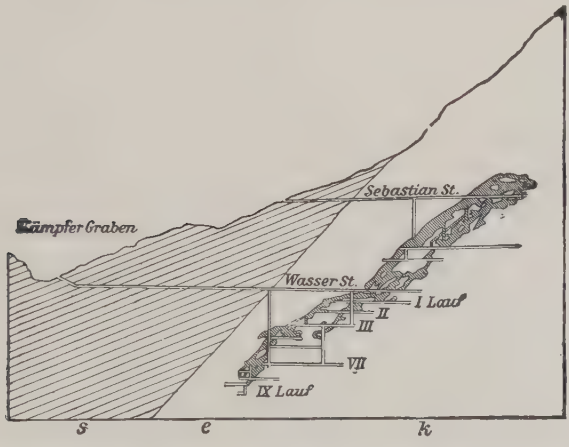


Fig. 232.—Section of the Johanni Clam orebody, north-south section. (Posepny.) s, shale; k, ore-bearing limestone; e, orebodies.

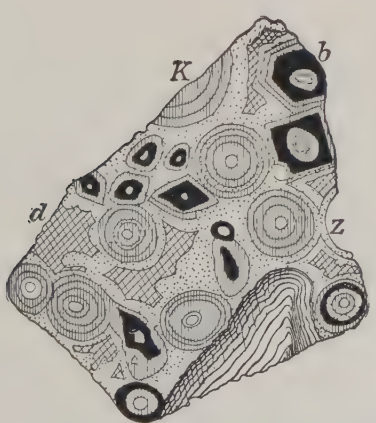


Fig. 233.—Tubular ore from Raibl. (Posepny.) b, galena; z, sphalerite; k, pyrite; d, dolomite spar.

Fig. 234.—Tube-shaped aggregate of galena crystals from Raibl. (Posepny.)

shape are exceedingly irregular, but their whole position and arrangement show such a dependence on the fault seams that both the corrosion of the cavities and their subsequent filling must have proceeded from

these fissures. Fig. 231 shows this dependence, and Fig. 232 shows the arrangement of the deposits on a large scale.

Three systems of fissures in particular come under consideration: (1) The Abend- und Morgenblatt, together with the Johanniblatt. (2) The fissure system of the Struggl ores series. (3) The fissure system Vincenzi-Aloisi-Josefi. They succeed one another in an east-west direction. The first three meet at an angle of about 33° and form the boundaries of orebodies that extend downward along the fissures.

The orebodies occur in columnar shoots which overlap on the north as the depth increases. The most important sulphide orebody is the main ore shoot between the Abend- und Morgenblatt. It forms a plate 50-140 m. (164-489 ft.) long in the strike and 30-70 m. (98-229 ft.) thick, dipping at 45°, parallel in its strike to the strike of the fissures, contiguous to them, and very irregular. This train of ore masses is at present exposed to a vertical depth of 450 m. (1478 ft.).

These sulphide orebodies consist of banded zinc-blende in very thin crusts (schalenblende), of non-argentiferous coarsely crystalline galena, with some iron pyrite and dolomite in concentric crust-shaped deposits, parallel to the walls of the cavities, but not conformable to the stratification. The dolomite, being the youngest mineral, is apt to form the drusy center, often still studded with barite crystals. Calcspar, zinc spar and white lead ore also occur as secondary decomposition products. A filling of pre-existing cavities is probable, particularly for the 'pipe' ores described in great detail by Posepny. They are obtained from the central part of certain orebodies, where granular dolomite predominates as the relatively youngest deposit, for example from the Struggl mines, seventh level. They consist of broken, hollow stalactites or tubes, composed in concentric layers of diverse material, chiefly galena with altered pyrites, blende, also cadmia and cerussite and frequently enclosed in a matrix of dolomite spar. Some of them are tubular aggregates of nothing but galena octahedrons. The cross-section is not always circular, but often quite irregular. The length of the fragments may amount to 10 cm., the diameter to 2 cm. (see Fig. 233 and Fig. 234, after F. Posepny).

In the 'hanging wall orebody' the so-called slate ore sometimes occurs, stratified dolomite with intercalations of blende and galena.

Between the sulphidic orebodies of the Abend- und Morgenblatt and those of the Vincenzi-Aloisi-Josefi-Blatt lie the calamine deposits of the second field. At this place the limestone is directly replaced by calamine, etc., along fissures and without previous formation of cavities, in such a way that unmineralized cores sometimes remained. Occasionally, the detailed structure of the original rock is retained by the calamine, as for

instance the cellular structure of the so-called 'Rauchwacke,' which consists of a skeleton of thin smooth cell walls representing the fillings of cracks in the limestone, the limestone being in part dissolved away or left only in separate decomposed splinters. The cell walls have subsequently been changed to calamine and covered by botryoidal clusters of that mineral, while the former cavities have been filled with a zinciferous earthy brown hematite, the so-called 'Moth' (see Fig. 235).

The Raibl cadmia consists mainly of zinc spar (red cadmia), more rarely of zinc bloom (white cadmia); hydrosilicate of zinc occurs but rarely. Towards the outcrop the zinc ores gradually give way to brown hematite.

Fig. 235.—Cellular cadmia from Raibl. (Posepny.)

Limonite and unctuous, ochrous, yellow, greenish or brown clays also occur in cavities in the cadmia masses.

Interesting conditions were disclosed by breaking into the 'grotto,' a cave tapped in 1892 in the 7th Johann-Firstenlauf. This cave connects with the east fissure, and its walls are coated with stalactites of blende and cadmia, as well as with crystals of galena, cerrusite and wolfenite. The latter minerals may be of secondary nature and deposited by descending waters.

Mining at Raibl began at an unknown date in the Middle Ages. In 1762, the Treasury purchased several shares in the mines and this led to the stimulation of the industry. In 1898, the Raibl field produced 2,046.9 tons of lead ore and 320.6 tons of lead, besides 12,384.9 tons of zinc ore.

14. *The Lead Deposits of Bleiberg in Carinthia*[1].

Bleiberg, which is situated about 12 km. (7 miles) west of Villach in Carinthia, is next to Raibl the most important lead and zinc deposit of

[1] F. Mohs: 'Die Gebirgsgesteine, Lagerungsverhältnisse und Erzlagerstätten zu Bleiberg in Kärnthen,' 1810 (manuscript). C. Peters: 'Ueber die Blei- und Zinklagerstätten Kärnthens,' *Oesterr. Zeitschr.*, 1863, p. 173. E. Suess: 'Geogn.-Berg-

Carinthia, its mines being many centuries old. The town lies in a deep gorge between the Dobratzsch at the south and the Erzgebirge at the north[1]. The first named mountain is well known on account of the great land slide of 1348, which fell into the Gail valley. The valley, according to Geyer, is a syncline cut through by the Bleiberg fault, which has dropped down the north flank (Erzberg) of the syncline, as compared to the south flank (Dobratzsch).

The Bleiberg deposits like those of Raibl lie in the ore-bearing limestone immediately below the Triassic Raibl slates. At Bleiberg the ore-bearing limestone is dolomitic in greatly varying proportions ($MgCO_3$ 0.1-40%), and often encloses minute quartz crystals. Because of its fissured condition this limestone, which is here a fetid bituminous rock, is permeable to water, just like the principal dolomite bed overlying the Raibl slates, while the slates are impervious.

The main mass of the Erzberg consists of the ore-bearing limestone. Overlying slates and swinestone are seen only near Rubland on the north and southward at the Bleiberg valley, the dip at the first place being north, at the latter south. These rocks represent the ends of a dissected arch, remnants of a solid anticline that once spanned the mountains but is now denuded. The entire south flank of the mountain is lowered to the southward by a great number of faults, individually of but very little throw, but aggregating a considerable amount, and breaking the mountain mass into many separate blocks.

The ore deposits of the Bleiberg, like those of Raibl, are metasomatic replacements with distinct cavity fillings, and are found with very few exceptions in the ore-bearing limestone. The cavities have the form of pipes or tubes (Schlauch-form, Posepny's term). The axial lines of the ore pipes (as pointed out by the Mohs at the beginning of the 19th century) are formed by the intersection of two planes, viz.: the bedding plane of the ore-bearing limestone and cross fissures. Some bedding planes "prove to be especially favorable or rich," and the same is also true of certain fissures. The fissures are characterized by an abundance of clay, the bedding planes by distinct evidences of water circulation. Sometimes, too, the pipes of ore occur in the immediate neighborhood of the so-called cross slates, or intercalations of slates in the ore-bearing limestone which traverse it across to the bedding. They are alleged to be Raibl slates pressed into fissures. Most likely they are fault clays.

männ. Skizze von Bleiberg,' *Oesterr. Zeitschr.*, 1869, pp. 259-262, 266, 267. F. Posepny: 'Ueber alpine Erzlagerstätten,' *Verh.* d. k. k. geol. Reichsanst, 1870. Hupfeld: 'Der Bleiberger Erzberg.' *Zeit. f. Prak. Geol.*, 1897, pp. 233-247, gives full review of literature.

[1] G. Geyer: 'Zur Tektonik des Bleiberger Thales,' *Verh.* d. k. k. geol. Reichsanst, 1901, pp. 338-359.

How far down the columnar ore shoots, or rather the line of such 'pipes' continue, has not yet been ascertained. At the present time the very deepest, lying more than 400 m. (1312 ft.) below the floor of the valley in the Kreuther field, are the richest. In every case, however, they are restricted to a zone 500 m. (1840 ft.) wide of the ore-bearing limestone in the neighborhood of the slate. Detached occurrences of ore, for that matter, are also found in the slate itself and in the fetid limestone. Even in detail the orebodies are clearly seen to follow the planes of rock parting, as shown in the section, Fig. 236.

Fig. 236.—Section across the orebodies of Wetterthürverhau.

The following minerals constitute the vein filling: (a) Primary: galena, zinc-blende, marcasite, barite, fluorspar, calcspar, dolomite spar. (b) Secondary: cerussite, plumbocalcite, anglesite, yellow lead ore (wulfenite), zinc spar, hydrosilicate of zinc, zinc bloom, brown hematite, anhydrite and gypsum. Anhydrite occurs in very considerable bodies. Asphaltic substances were also observed[1].

[1] H. Höfer: 'Erdölstudien,' *Sitzungsber.* Kais. Ak. W. Vienna, Math.-Phys. Cl., Vol. CXI, part I, July, 1902, p. 27. This remarkable work, recently published, discusses the widespread distribution of bituminous material in ore deposits of all kinds, including veins, and the significance of this fact in its relation to ore genesis. The author explains the paragenesis of argentite, native silver, and anthracite in the Kongsberg veins, as due to the action of currents of CO_2, the reaction, as experimentally determined, being $2Ag_2S + CH_4 = 4Ag + 2H_2S + C$.

The great purity of the Carinthian galena, its freedom from antimony and copper, have made the Carinthian 'virgin lead' famous. The Bleiberg-Kreuther field in 1898 produced 4,681.5 tons of lead ore (including 53.3 tons yellow lead ore) and 3,640.2 tons of lead, as well as 3,088.8 tons of zinc ore.

Quite similar conditions are exhibited by the lead mines at Rubland in lower Carinthia, which stopped operations in 1897[1].

15. *The Silver- and Gold-bearing Lead Deposits of Mapimi, Durango, Mexico.*

The vast deposits of silver- and gold-bearing lead ores at Mapimi, in Mexico, according to E. Naumann[2], form a system of columnar ore shoots in the middle Cretaceous limestone. The ore shoots are associated with great fissures and lie in a downthrown area, a "zone of collapse," at the foot of the Bufa, a block of Cretaceous limestone 2,400 m. (8,872 ft.) high. The main deposit is the Ojuela, a pipe of ore 30 m. (98 ft.) in diameter and opened to a depth of 500 m. (1,640 ft.) Judging from specimens seen, the mass filling these tube-shaped masses has the following character:

In the undecomposed condition, as it appears in the so-called arsenopyrite depression of the Ojuela, the ore minerals are galena, arsenopyrite, chalcopyrite, pyrite, zinc-blende, boulangerite, red silver ore, gray copper and antimonite; the gangue is of quartz, fluorite, barite, calcite, rhodochrosite and ankerite. A compact mixture of arsenopyrite, galena, pyrite, zinc-blende and fluorite decidedly predominates. The minerals also occur crystallized in druses. The boulangerite is usually intimately coalesced with asterated quartz. As the ground-water in the mines of the Ojuela has been reached only at great depth, beyond 500 m. (1,640 ft.), probably because the fissures draw off the water, the great downward extension of the gossan is not surprising. Within this gossan formation there are found, as secondary minerals, cerussite with remnants of yet undecomposed galena, hydrated lead antimonite (in part formed direct on the boulangerite), wulfenite, cadmia (calamine and smithsonite), limonite, pyrolusite and antimony ocher. True secondary silver ores are indeed not visible, but may be present as finely divided cerargyrite, since there is considerable silver in the ore. Mention must also be made of secondary calcspar and aragonite.

[1] R. Rosenlecher: 'Die Zink- und Bleierzbergbaue bei Rubland in Unter-Kärnthen,' *Zeit. f. Prak. Geol.*, 1894, pp. 80-88.

[2] E. Naumann: 'Ueber eine Reise nach Mexico,' Z. d. D. G. G., 1899, Vol. L, part III, p. 106.

The Mapimi ores contain on an average 18% lead, 0.06% silver and 6 g. of gold per ton. The output in 1897-8 (to June 2d) was nearly 70,000 tons.

To explain the origin of these deposits, E. Naumann imagines that the ore chimneys were formed by the explosive pressure of steam and by the widening of the pipes by the rising of acid fumaroles. As the filling of the Ojuela contains no pyroclastic products, such violent processes seem rather improbable. However, the rising of hot springs, mineralizing the limestone and undoubtedly following the intersections of tectonic fissures, may have been an echo of volcanic processes. It is to be noted that the limestones at the Sierra de la Cruz near the Ojuela and near San Ramon have undergone contact metamorphism by plutonic masses. They carry yellow garnets, vesuvianite, light-colored mica and green translucent spinals, or they are marmorized. The formation of the ore may also be connected with these processes.

16. *Silver-Lead Mines of Santa Eulalia, Chihuahua, Mexico*[1].

The great lead deposits of this locality are about 12 m. southeast of the city of Chihuahua.

The mines are in a northeast to southeast range of arid and barren mountains which are formed of Cretaceous limestone, cut by eruptive rocks, and in part covered by rhyolite tuffs laid down on very irregular and rugged surfaces. The limestones form a dome with gentle dip (5° to 15°). The mines all occur in this limestone dome, which is now deeply scored by narrow gulches. The ore deposits form great masses of irregular shape, in the limestone, following and in part limited by stratification planes. Most of the orebodies lie on the floors of great caverns, and hence correspond to the type called by Newberry "chamber deposits." There is unquestioned evidence, however, that these caverns are formed by later circulating waters. The orebodies are sometimes connected by fissures, and are themselves more or less connected either by films of red clay or by a limestone checked and netted by minute fractures filled with iron oxide. The ores are mainly oxidized and consist of more or less impure cerussite, sometimes showing nucleal cores of galena. The replacement of the limestone is indicated by lines of chert corresponding with similar lines in unaltered limestone walls, and by the presence of silicified fossils in the ore. The ore carries variable amounts of silver, but averages about 25 ounces per ton. The mines were discovered in 1591, but did not become noteworthy producers until 1705.

[1] From observations of W. H. W. See 'Notes on Mines in Chihuahua,' *Trans.* Am. Inst. Min. Eng., Vol. XXXII, 1902, p. 396. Also, R. T. Hill, same vol., p. 174. Jas. P. Kimball, Am. Jour. Sci., 2d series, Vol. XLVIII, 1869, p. 379.

The total production on which taxes were paid for the years 1705 to 1791 was $112,000,000. The district is now one of the chief producers of Mexico.

17. *The Sierra Mojada Silver Mines, Mexico.*

The mines of this name[1] are situated on the northern foot-slopes of a steep mountain front rising 3,000 ft. above a narrow desert valley. The mountain is formed of Cretaceous limestones, mostly horizontal, which are older than and lie under volcanic breccias and tuffs forming the lower foot-slopes. The ore deposits occur either along the contact between these

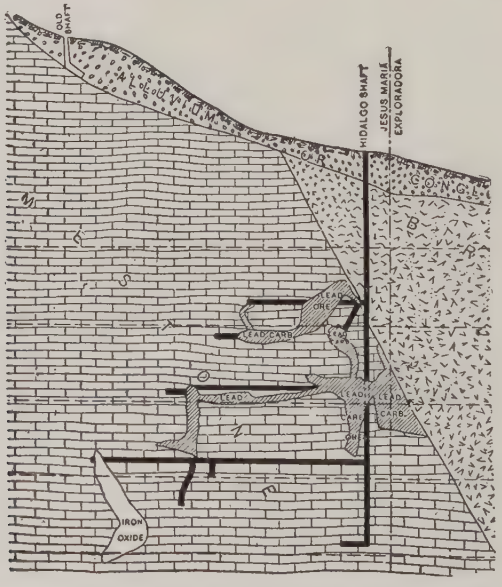


Fig. 236*a*.—Cross-section through the orebodies at Sierra Mojada, Mexico. (Malcolmson.)

Orebodies in limestone. Breccia of volcanic rock to right of fault. Capping of conglomerate.

rocks, or in the limestone. The great orebodies are 'chamber' masses in part along fissure lines transverse to the contact, but connecting with the contact orebodies. These masses occur more or less along the bedding planes, are roughly horizontal, and 2 to 40 ft. thick, often having pipe-like extensions for 100 ft. or more downward into the limestone. These carbonate orebodies carry 12 oz. silver per ton, and 15% lead. The impregnations consist of limestone, with disseminated silver chloride, and with the addition of silica when near the breccia contact. The contact

[1] James W. Malcomson: 'The Sierra Mojada, Cohuila, Mexico, and its Ore Deposits' *Trans.* Am. Inst. Min. Eng., Vol. XXXII, 1902, p. 100.

orebodies are less important, and in one case consisted of copper ore. The district produced 200,000 tons of ore annually from 1886 to 1900, but is now declining.

(e) Epigenetic Stocks of Gold Ore.

1. *Refractory Siliceous Gold Ores of the Cambrian Rocks, Black Hills, South Dakota*[1].

These deposits occur in the Bald Mountain, Portland, Crown Hill and Sheeptail Gulch districts of the Black Hills in South Dakota.

The almost horizontal Cambrian, resting unconformably on upraised Algonkian schists, usually begins with a basal conglomerate. Above this a quartzite frequently follows, and immediately above this a calcareous

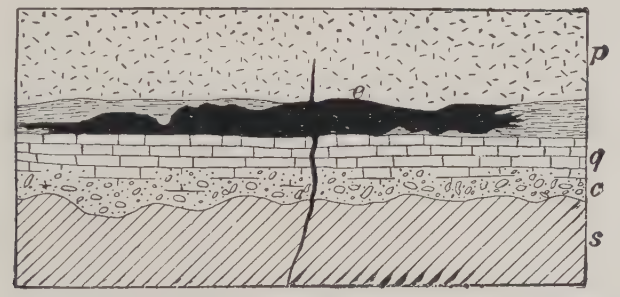


Fig. 237.—Cross-section of an orebody of the American Express Gold Mine. (Irving.) p, porphyry; q, quartzite; c, conglomerate; s, crystalline schist; e, ore; height, 5m.

sandstone or impure dolomite, usually overlain by the ordinary sandstones and slates of the formation, sometimes with porphyritic intrusive sheets.

The orebodies are found within the dolomitic strata immediately above the quartzite, in some cases also within calcareous horizons situated higher. In form they are very irregular, but are always flat extended masses, never exceeding, in a vertical direction, the thickness of the calcareous layer. Along their sides they appear dovetailed, as it were, with the normal stratified rock (see Fig. 237). Longitudinally they are always traversed by a vertical fissure (a 'vertical'), carrying the same ores, which may be followed for some distance into the underlying strata.

The ore is a hard, brittle rock composed of secondary silica and carrying, when unoxidized, pyrite, fluorite and other accessory minerals. Although

[1] F. C. Smith: *Trans.* Am. Inst. Min. Eng., Vol. XXVII, p. 415. J. D. Irving: 'A Contribution to the Geology of the Northern Black Hills,' *Annals* New York Ac. of Sc., 1899, Vol. XII, No. 9, pp. 296-311. Also, 'Economic Geology of Northern Black Hills,' Prof. paper No. 36, U. S. Geol. Survey, 1904.

the ores contain from 124-250 grams of tellurium, 10-18 grams of gold and up to 342 grams of silver per ton, yet neither free gold nor tellurides as such can be recognized in them. Some thallium has also been found in them.

These deposits manifestly represent replacements of calcareous strata. The fissures were channels along which the ore-bearing solutions rose from the depths. In composition, but not in form, these deposits are analogous to the lode-shaped gold ore deposits of Cripple Creek. Like these they are characterized by a tellurium content and by the presence of quartz with fluorspar. Like Cripple Creek the Black Hills contain phonolites, so rare elsewhere in North America. The shafts by which the ore deposits were opened passed in part through phonolitic intrusive masses, and the ore-bearing fissures along which the mineralization of the limestone took place sometimes cling to the selvage of dikes of phonolitic or porphyritic rocks. The ores average $15 per ton in the main area.

It is to be noted that, according to J. D. Irving, zones of mineralization of the same composition are also found in the Carboniferous limestone of the Black Hills (in the Ragged Top District) where, however, they usually pass vertically through the strata (*l. c.*, p. 311).

2. *The Gold Deposits in Dolomite at Pilgrim's Rest in the Transvaal, Africa.*

Pilgrim's Rest lies in the Lydenburg district in the midst of the mountainous tract between the Olifant River at the north and the Crocodile River at the south. While the neighboring lowland is mainly made up of granite, the mountain range at Pilgrim's Rest, culminating in Mount Mauch, 2,617 m. high, is composed, according to J. Kuntz[1], of a system of slightly tilted strata whose sequence from above downwards is as follows:

3. Sandstones, alternating with clay slates, with intruded sheets and dikes of diabase and diorite.

2. Dolomite, with intercalations of slate and hornstone, 150-250 m. thick.

1. Sandstone, with two non-auriferous, or at any rate non-workable, conglomerate beds and some layers of slate.

The gold deposits are found intercalated in the dolomite at very different horizons, forming rather irregular stratiform bodies, in general parallel

[1] J. Kuntz: 'Ueber die Goldvorkommen im Lydenburger District,' *Zeit. f. Prak Geol.*, 1896, pp. 433-441. P. R. Krause in the Aufsatz: 'Erzführung der Witwatersrand-Conglomerate,' *Zeit. f. Prak. Geol.*, 1898, pp. 19-21. A. Bordeaux: 'Etudes sur les champs aurifères de Lydenburg,' etc., *Ann.* d. Mines 9, XI, Paris, 1897, p. 300. J. G. Bousquet: *Jaarrapport* van den Staats-myning. over het jaar 1896, Pretoria, 1897.

to the bedding, but in detail often traversing it. They occur as follows from above downward:

Upper group.....	Theta, Chi, Psi, and Jubilee reefs. Clewer or Morgenzon reef. Beta and Frankfort reefs.
Lower group.....	Glynn reef. Spitzkop reef. Peak reefs.

The thickness of these deposits varies greatly. In Glynn reef it is from 0 to 2.13 m., in Theta reef 0 to 2 m., in Beta reef 0 to 0.6 m., rarely more. Clewer reef is divided, by a layer of wad, dolomite or hornstone, into two stringers, whose total thickness varies between 0 and 1.5 meters. Most of the deposits rest on the dolomite, projecting into it in a number of embayments, while the ore is often overlain by a bed of hornstone and in the Beta mine also by an intrusive sheet of diorite. Displacements sometimes occur, as at the Clewer mine, whose orebody is faulted by a dike of diabase porphyry. As all the workings are as yet above ground-water level, the mineral composition of these deposits is known only in the zone of oxidation. Here their main mass consists of quartz that is sometimes compact and hard, but is usually spongy and porous, and at times quite like pumice-stone and easily crumbled into dust. The hard portions are the poorest. The gold is very finely disseminated, and but rarely recognizable with the naked eye. The orebodies also contain much iron ocher, wad, lumps of copper carbonates, especially azurite, and, at certain points, according to specimens at hand, bismuth ocher.

Through the formation of cavities in the dolomite after the deposition of the ores, and the falling in of the roof of the caverns, the deposits occasionally have been changed into a mass of débris. As the lateral leaching out of the dolomite parallel to the joints of the strata has somewhat diminished the thickness of that rock, the overlying strata, with the deposits here, have acquired a steeper dip outward. The dolomite, whose stratigraphic position suggests its identity with the Malmani dolomite, is (in the Pilgrim's Rest area) also traversed by steeply dipping gold quartz lodes. These vary from the thickness of a sheet of paper to 6 in. and lie about 15 m. (50 ft.) from one another. Despite their slight thickness, they sometimes yield a large output of coarse gold. They are said to be richest where they traverse the slates, poorer in the sandstone, and very poor in the dolomite. They are in close proximity to diorite dikes. The bed-like masses of gold ore are distinctly recognizable as metasomatic replacements of the dolomite. It seems probable that the veins just mentioned represent the channels of supply from which the auriferous solutions penetrated laterally into the rock.

A few gold deposits also occur in the slates of the upper sandstone horizon—for example, in the Finsbury and Nooitgedacht reefs, but are of slight importance.

In contrast with the Johannesburg area, the mining operators of this district have to battle with many difficulties, as the region is very rugged and the work requires a good deal of timbering, which, in this poorly wooded country, is very expensive. Nevertheless, some mines are in successful operation there.

Gold Ores of Bannock, Montana.

Deposits similar to the gold deposits of Pilgrim's Rest are found in the Golden Leaf mines of Beaverhead county, in southwestern Montana, described by R. W. Barrell.[1] Cavities partly filled with gold-bearing quartz and connected by narrow quartz stringers are there found in the limestone close to its superposition on the granite. Stringers of gold quartz are also noticed in the granite. The deposits are garnetiferous rocks impregnated with free gold and tellurides of gold, in the zone of intense contact metamorphism of Cambrian limestones altered by a diorite stock which has domed the beds.

(f) Epigenetic Stocks of Antimony Ores.

The Antimony Deposits of Kostainik[2] in Servia.

Antimony deposits forming replacements of limestones have been described from Servia, in the district of Kostainik. Besides these truly metasomatic antimonial deposits, vein-shaped deposits also occur at that locality, and for convenience and brevity we will discuss both together.

The antimony deposits of the environs of Kostainik lie in the extreme western part of the district, in the mountainous wooded basins of the Styra and Bornia rivers, which flow into the river Drina that forms the international boundary line; also in the head-water area of the Grabiteba river. The mineral districts occur along a line 16 km. (9.6 miles) long, and 1.5 km. (0.9 miles) wide, running northwest-southeast.

The main mass of the rocks in that locality is formed of light-gray to ash-gray limestones, with laminated stratification and probably of

[1] R. W. Barrell: 'The Mineral Formation of the Golden Leaf Mines,' *The Engineering and Mining Journal*, 1897, LXIV, p. 64. W. H. Weed: 'Ore Deposits near Igneous Contacts,' *Trans.* Am. Inst. Min. Eng., Oct. 1902, p. 18.

[2] R. Beck and W. von Fircks. 'Die Antimonlagerstätten von Kostainik in Serbien,' *Zeit. f. Prak. Geol.*, 1900, pp. 33-36.

Triassic age, overlain conformably by gray and blackish soft clay slates, in part also by distinctly clastic graywacke slates.

These limestones and slates are broken through at many points by biotite-trachytes, and at Ravanitza and probably elsewhere also by hornblende andesites of trachytic habit. These eruptive rocks form dikes, sheets and stocks within the strata, and also perhaps effusive lava flows. The antimony deposits are intimately connected with the igneous rocks.

The ores consist exclusively of stibnite, which has been secondarily altered into valentinite and stiblite, as well as into other forms of antimony ocher, and is accompanied by quartz and calcspar. In addition, there are very subordinate amounts of a secondary development of small, imperfectly developed crystal groups of native sulphur and sharply developed crystals of senarmontite, up to a millet grain in size.

The ores appear in three different forms:

1. *Tufts and stringers of stibnite, quartz and calcite in decomposed trachyte.*—Such ores are found in the mines of Kik and Stolitza.

2. *Antimony veins in the slates.*—In this type, of which the only example known is at Rovinè, we are dealing with a compound vein dipping at 30°. Between the two parallel bounding fissures, which intersect the stratification and schistosity of the country rock, lies a zone sometimes over 1 m. (3.28 ft.) thick, of very numerous stringers, mostly transverse, like the rungs of a ladder. The foot-wall fissure is always the richest. The hanging wall is mostly barren. The transverse stringers are cut off at the two wall fissures and are rich in stibnite, with quartz and calcspar. Outside of the zone enclosed by the leading fissures only barren calcspar stringers occur.

3. *Interbedded ore masses.*—At most of the numerous small mines and prospects stratiform deposits are worked, which are underlain by limestone and overlain by slates. A trachyte intrusion is always found near by, and narrow apophyses (*i. e.,* branches) of that rock often form the walls of these deposits or cut through the ore masses, sometimes in a direction parallel, sometimes forming an acute angle with them (Fig. 238). The deposits consist of a dark, very finely crystalline groundmass of quartz, intimately intergrown with tufts of stibnite. The dark color of the quartz is due to microscopic particles of bitumen or coal, which are especially abundant between the limiting planes of the minute polyhedric quartz grains, but also occur as inclusions in their interior. The stibnite has mostly been superficially altered into antimony ocher, stiblite or valentinite, but in many cases it has been leached out again entirely, so that the gray quartz merely contains the hollow moulds of the sheaves of antimony glance. Sometimes the quartzose ore has been crushed and

re-cemented by quartz or calcspar. In such breccia-like portions, quite irregular druses occur, whose walls are studded with quartz crystals and also show here and there minute crystalline aggregates of native sulphur and crystals of senarmontite. Sometimes, as at the Zavorie II mine, the quartzose orebodies are traversed obliquely by calcspar stringers.

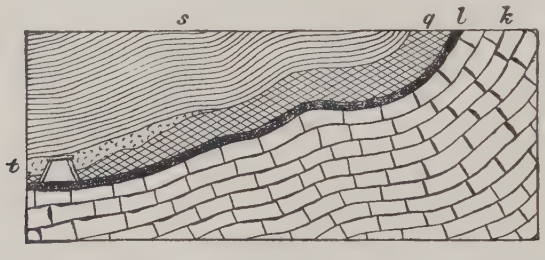


Fig. 238.—Bed-like deposit of antimony ore near Kostainik.
q, quartz layer with antimony ore; l, clay; k, limestone; s, clay slate; t, trachyte.

These ore masses are at some points intercalated between the slate and the limestone, and thus resemble beds, especially at points where, owing to folding, the parting plane between these rocks shows a wavey course in the cross-section.

In other cases, however, the ore-bearing quartz mass is seen to extend into the underlying limestones with very irregular borders, often cutting through the bedding, suggesting that considerable portions of calcium

Fig. 239.—Cross-section of a bedded antimony deposit in limestone at the Zavorie III Mine.
a, antimony ore; the remainder as in Fig. 238.

carbonate have been leached out and replaced by the quartzose ore. This is exhibited especially in Fig. 239, representing a cross-section through the very rich ore mass of Zavorie III mine, which is 2 to 6 m. (6.5 to 16.4 ft.) thick. The cavity found in the underlying limestone was followed to a distance of several meters as an irregular groove. At the borders of

the orebodies, both above, along the boundary of the slate or trachyte, and below, thin layers of clay are not infrequently found. Clay fissures also occur which cut obliquely across the orebodies, as for example at another place in the Zavorie III.

All the phenomena just described seem to indicate that the antimony ores of Kostainik were deposited from solutions which penetrated into the solid and already folded sedimentary rocks of this region. Whether or not these solutions derived their antimony content from a deep-seated mass of trachyte, the uprising waters being an aftermath of the processes of eruption, cannot at present be determined with certainty, though it certainly appears a very plausible theory. The solutions left their deposits not only in the fissures and clefts which formed their main channel, but penetrated also laterally into the joints between the strata of the limestone, this result occurring wherever a relatively impervious rock, the slate, checked their further rise. At the boundary of the rock they stagnated, dissolved the underlying calcium carbonate and exchanged it for the mineral burden which they had brought up with them.

Antimony Deposits in Italy.

A series of stock-shaped occurrences of antimony ore found at the boundary between the Rhaetic limestone and the Permian slate occur in Tuscany (as at Rosia near Siena, at Orbetello in the province of Grosseto and elsewhere). At Rosia the stibnite is accompanied partly by calcite, partly by quartz. The country rock is silicified. Fine groups of stibnite crystals, superficially altered to antimony ocher, are known from that locality, which are studded with crystals of native sulphur and valentinite.

Mention should also be made of the antimony stocks in the Su Suergiu mine, near Villasalto in Sardinia, which are enclosed in Devonian Carbonaceous slates near the boundary of the Silurian.

Antimony Deposits of the United States.

Antimony-bearing quartz veins are common in California and Nevada, and were worked ten or fifteen years ago. A remarkable bedded deposit occurs on Iron Creek, Coyote Co., southern Utah, the ore being an impregnation of a sandstone bed just above limestone. Stibnite occurs in tufts and radial masses, in layers ½ inch to 30 inches thick, there being no other mineral present. The deposit is regarded as an impregnation of porous sandstone layers by mineralizing hot waters, analogous to those now depositing stibnite in alluvial gravels at Steamboat Springs, Nevada.

C. CONTACT-METAMORPHIC ORE DEPOSITS.

By this term we understand the epigenetic bedded deposits and ore stocks formed within stratified rocks under the influence of contact metamorphism near or along the boundary between plutonic eruptive masses and stratified rocks. The most important criterion for the recognition and distinction of the contact-metamorphic ore deposits as compared with the other epigenetic bedded deposits and ore stocks, is the mineralogic composition. The ore is always characterized by the presence of certain minerals which we know elsewhere to be typical of igneous contact zones. Where the ores, as is usually the case, have metasomatically replaced limestones, dolomites or other rocks consisting only partly of calcium carbonate, we find, as contact minerals, garnet, epidote, light-colored pyroxenes, wollastonite, vesuvianite and other lime silicates. Contact-metamorphic ore concentrations in shales may be accompanied by andalusite, chiastolite, cordierite, scapolite, etc. The diagnosis becomes difficult when the normal country rock belongs to the crystalline schists. A sharp separation of some supposedly epigenetic ore deposits from the contact-metamorphic deposits is not yet possible. In view of the great similarity in the appearance of certain varieties of regional metamorphism with that of contact metamorphism, this can not be deemed surprising. We have already in the description of the deposits of Schwarzenberg and of Pitkäranta pointed out this relation and the kinship between the two categories, which may perhaps on further investigation prove to be even closer.

There is a very close genetic relationship between the contact-metamorphic ore deposits and magmatic ore segregations. In fact, in both types the metal content is derived from the magma.

Hence W. H. Weed, in his recent very suggestive scheme for a scientific classification of ore deposits[1], has very properly assigned to the contact-metamorphic deposits a place immediately after the magmatic segregations.

The most important ore of contact-metamorphic deposits is magnetic iron ore. Sulphide copper ores are next in importance, while a great number of other ore minerals are of lesser importance.

In many instances vein-shaped deposits are connected with contact-metamorphic ore beds and ore stocks. In fact, many of the deposits of contact-metamorphic mining districts are of diverse form, but have been bunched together in the descriptions given herein.

[1] 'The Genetic Classification of Ore Bodies,' Geol. Soc., Washn., D. C., Jan. 14, 1903. *The Engineering and Mining Journal*, Feb. 14, 1903, 'Ore Deposits, a Proposal and a Discussion,' 1903.

1. *The Ore Deposits in the Contact Area of the Granite of Berggiesshübel, in Saxony*[1].

The ore deposits of Berggiesshübel, in the so-called Elbthalgebirge of southeastern Saxony, represent a typical example of contact-metamorphic ore deposits that have been investigated with particular care, and will for that reason be described first, and with some detail, although the deposits have long lost their economic importance.

At Berggiesshübel several granite stocks occur in gently dipping slates. One of these, which, by its size and the extent of its contact phenomena, occupies the first rank, is the granite stock of Markersbach. Close to its western edge lies the mining field of the old mining town of Berggiesshübel. At this place the outcrops of the various beds of the Phyllite and lower Silurian formations are well exposed and distinctly seen abutting against the granite boundary, and from these exposures and various minor workings it is known that the surface of the eruptive stock dips at a low

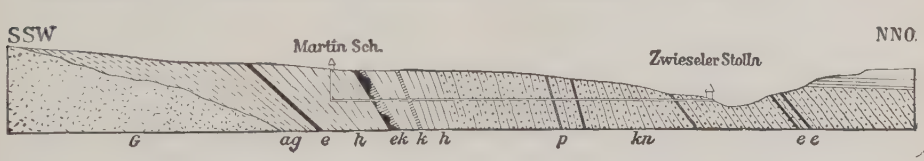


Fig. 240.—Section across the contact zone of Berggiesshübel.

G, Markersbach granite; ag, andalusite-mica rock; h, hornblende and salite schists; k, knotted slate; e, ore-bed; k, marble; p, quartz porphyry; t, Lower Turonian and Cenomanian.

angle beneath the slates. The sedimentary rocks which adjoin and in part overlie the granite have been subjected to strong contact metamorphism.

In the Silurian formation, the clay slates were changed into hornstones (Hornfels), horn schists and nodular schists, the diabase tuffs into various hornblende schists, especially actinolite schist, also banded salite-hornblende schists. The limestone beds, intercalated in the clay slates and especially in the tuffs, were, however, turned into deposits of marble or in part into salite-garnet rock beds, or finally into magnetic iron ore beds (see Fig. 240).

These limestone beds may be followed in a northwest-southeast direction, along their strike, for long distances, being exposed in many openings, deep limestone quarries and natural exposures from Maxen across the villages of Biensdorf and Gersdorf, to the point where they enter into the contact

[1] R. Beck: 'Erläuterungen zu Sect. Berggiesshübel der geol. Spezialkarte von Sachsen,' Leipzig, 1889, pp. 25-60. H. Müller: 'Ueber die Erzlagerstätten der Umgegend von Berggiesshübel,' part of geol. map of Saxony, Leipzig, 1890, with map of veins and cross-section. Gives review of literature.

area of the granite. Over this entire distance, however, these limestones are devoid of ore, with the exception of a few insignificant deposits of red and brown hematite ore, which occur for example at Nenntmannsdorf, at the slate-limestone parting.

Within the vicinity and influence of the igneous contact, however, the calcium carbonate has been partly or entirely driven out of these beds, and replaced by the material from invading siliceous and mineralizing solutions, forming salite and garnet, as well as magnetite and various sulphide ores. The distribution of the marble, calcium silicates and ores within the beds is very remarkable and varied, and clearly shows the character of this kind of replacement.

First it is to be noted that the marble still shows distinctly the stratification of the originally dense Silurian limestone from which it was derived. Furthermore, the alternation between thin limestone strata and tufaceous beds found in the Silurian of that locality is repeated in the contact area between marble and hornblende schist, except that the limestone, whenever it formed thin streaks and layers, is for the most part completely changed into a light greenish pyroxene rock.

In the thicker limestone strata of the contact zone there is frequently a sequence of several beds of marble, with intervening beds of salite-garnet rock, alternating with garnet rock and magnetic iron ore. More commonly, however, quite irregular nests and lumps of magnetic iron ore are found in the midst of the marble, and cutting across its stratification. They often penetrate into the marble with jagged or stringer-like projections. Occasionally, as for example in the levels driven in limestone from the Hermann shaft, irregular vein-shaped masses of magnetic iron ore were observed even in the midst of the limestone. On the whole, the ore clings particularly to the lower boundary of the marble bed, frequently thickening and entirely displacing it for long distances, occasionally reaching a thickness of 5 m. (Fig. 241). Finally, the orebodies are traversed at times by branching stringers of garnet rock, forming a network. This shows that the ore mass was broken, but the supply of the garnet-making materials seems to have continued after this mechanical disturbance. That disruption took place during the recrystallization and alteration of the dense limestone into marble is furthermore indicated by the frequent stringers of coarsely foliated white calcspar which traverse the blackish marble as white bands. They seem to have been formed as primary veinlets during the metamorphic process, since they occasionally carry garnet.

Besides magnetic iron ore, the deposits of that region also carry copper ores, such as copper pyrite, bornite, copper glance, and rarely gray copper

ore. These yield a number of secondary copper ores, malachite, etc. Less frequent admixtures are pyrite, arsenopyrite, galena and zinc-blende.

While the immigration of all these ores into the limestone strata of the locality is beyond question, the origin of the metalliferous solutions is as yet doubtful. Two suppositions are possible. Either the metallic compounds in question were originally finely distributed in the country rock, especially in the diabase tuffs, and were carried into and concentrated in the limestone by contact metamorphism, after expulsion of its carbon dioxide, through a redeposition by the mineralizing agents proceeding from the granite; or they were brought up directly by the granite from a great depth and infiltrated into the country rock in solution in the superheated water of eruption. As all the hornblende schists and hornstones of

Fig. 241.—Section of the Mutter Gottes bed of Berggiesshübel.
h, hornblende schist; n, actinolite; k, crystalline limestone in magnetite.

the contact are also rich in iron, much more so than elsewhere away from the contact, the theory of the introduction of the ore by the granite has the greater probability.

The probability is increased by the fact that true veins are also known in this part of the contact zone, which carry copper ores and which in part pass through the ore-beds. They seem to represent the main channels of supply of the metallic solutions from the granite.

Finally, besides these copper veins, tin-ore-bearing stringers are also known in the beds of metamorphic limestone of that locality. They consist of orthoclase, fluorspar, quartz and lithia mica in zonal distribution. In their vicinity A. W. Stelzner also discovered tin-stone, accompanied by copper pyrite and pyrite as an impregnation in certain layers of the strata, consisting essentially of chlorite.

Thus the Markersbach granite mass is surrounded by a contact zone or halo of ore consisting of very diverse metallic compounds.

2. *The Magnetic Iron Ore Deposits of Schmiedeberg in the Riesengebirge, Germany.*

According to the recent investigations of G. Berg[1], the magnetic iron ore beds of Schmiedeberg also belong to the contact-metamorphic deposits.

Schmiedeberg lies on the north slope of the range, close below the pass leading from the Hirschberg basin over toward Landshut, within an extensive area of younger porphyritic granite. The ore deposits above the town, in the mines of the concession, lie, on the contrary, in a zone of steeply dipping, crystalline schists, with north-northeast strike, lying south of the granite. These rocks, to the northwest, consist mainly of gneiss-like Archean granites, with intervening layers of fine-scaly gneisses and mica schists. To the southeast the rocks consist of amphibole schists and chloritic mica schists with limestone beds. The ore beds form intercalations in a group of limestones, amphibolites, biotite and muscovite schists, adjoining the gneisses and mica schists. The limestones of this ore-bearing stratified series are always granular-crystalline, and, by their transition into lime-silicate rocks with garnet, salite-like pyroxene, epidote, amphibole, chlorite, vesuvianite, scapolite, fluorite, spinel and titanite, betray their contact-metamorphic alteration by the neighboring porphyritic granite. To a similar influence are probably due the horizontal veins, called "Riegel" (bars), of a pegmatite-like rock, traversing the ore deposits, and finally the concentration of the ore may itself be a contact phenomenon.

Ten ore beds are distinguished in the mines, but they do not all appear in any one cross-section. The thickness of the workable portions is usually 2 m. to 3 m. (6.5 ft. to 9.8 ft.), rarely more, though sometimes rising to 7 m. (23 ft.) Most of the ore beds are overlain by limestone and underlain by biotite schist or amphibole schist. In the granular magnetite of the beds, chlorite, garnet, pyroxene, epidote and calcite are interspersed, sometimes also pyrite, magnetic pyrite and copper pyrite. The sulphides, together with calcite, form stringers in the lime-silicate rocks, being evidently the last formed of the minerals.

Schmiedeberg is said to have been founded as a mining town as early as 1148. In recent years the mining industry, formerly subject to many vicissitudes, has entered on a renewed period of activity. In the year

[1] G. Berg: 'Die Magneteisenerzlager von Schmiedeberg im Riesengebirge,' *Jahrb.* d. kgl. preuss. Geol., Landesanst., 1903.

1899, the Bergfreiheit mine yielded 24,000 tons of iron ore containing 50% to 60% of iron.

3. *The Iron Ore Deposits of the Schwarzen and Gelben Krux, Germany.*

The magnetic iron ores of the Schwarzen and Gelben Krux, near Suhl, in Thuringia, may, as a result of the petrographic investigations by K. Schlegel[1], be positively classed as contact-metamorphic formations.

A tourmaline-bearing granite, carrying allanite and fluorspar near the ore deposit, has broken through Cambrian clay slates. Near the Krux mines the slates are transformed about the contact into hornstones, which at some points are characterized by cordierite, tourmaline and garnet, at others by andalusite, and sillimanite. Tourmaline-bearing quartzites also occur. The magnetic iron ores, which probably were worked as early as the beginning of the 10th century, belong to this contact zone. Their granular-crystalline mass always has fluorspar mingled with it, often also wolframite, molybdenite, hematite, allanite, barite and pyrite. Sometimes a good deal of quartz is added. From one of the abandoned shafts, greenish-yellow garnet rocks were also obtained, with intermingled calcite, barite, feldspar and magnetite. B. von Cotta mentions a tin content in the ores.

We are of the opinion that the ore deposits were derived from a contact-metamorphic mineralization of calcareous intercalations.

4. *The Contact Ore-Deposits of the Banat, Hungary.*

South of Temes river, which issues from Transylvania, a range of mountains, with a mean altitude of 800 m., extends from north-northeast to south-southwest toward the Danube and beyond it into Servia. This range consists first of strongly folded mica schist, gneiss, granulite and quartzite; next of mineral-bearing Carboniferous strata, red Permian sandstone and limestones of the Jurassic and Cretaceous.

The sediments just referred to represent the filling of great synclines of the Archean schists, and consequently extend in long troughs parallel to the main strike of the mountains.

A north-south fault fissure, recognizable for a great distance, extending far into Servia, traverses this mountain range thus briefly sketched, cuts off the Mesozoic strata sharply toward the west, and has been the path of invasion of younger eruptive rocks. The latter can be traced, not in

[1] K. Schlegel: 'Die Magneteisenerzlager vom Schwarzen Krux bei Schmiedefeld im Thüringer Wald,' *Z.* d. D. G. G., 1902, Vol. LIV, pp. 24-55; gives other literature of Krug von Nidda, H. Credner and B. v. Cotta.

perfect continuity, it is true, for a distance of 78 km. (46 miles) (see sketch-map, Fig. 242). These eruptive masses are in close genetic connection with all the ore deposits occurring in the Banat.

The miner in the Banat uses the name "syenite" to designate the rocks of varying development, of granitic, porphyritic, probably also felsitic structure. Von Cotta called them "banatites," Vom Rath and Niedzwiezki, after accurate petrographic investigations, called the most widely distributed type "quartz diorite," while Szabo calls it quartz-andesine-trachyte. Von Halavats having shown that the rock in question, southeast of Raffina, overlies a block of the Leitha limestone, it may without question be ranked among the younger eruptive rocks. According to Szabo's investigations, the banatites consist of triclinic feldspar, monoclinic amphibole, biotite and quartz, with which orthoclase is pretty constantly though subordinately intermingled. Hence the rock may be called andesite, or more accurately a quartz-andesite or dacite. It is to be noted, however, that the typical development of the rock possesses a crystalline structure, and a glassy groundmass is entirely wanting. For this reason, and from geological occurrences of the rock, it is inferred that we are dealing with an andesitic magma, rich in silicic acid, congealed under the sedimentary strata, and having the structure of a plutonic rock, while its branches may show a porphyritic or even felsitic character.

Where this dacitic rock came in contact with the Mesozoic limestones, it caused important contact phenomena, as would be expected from its plutonic nature. On the one hand, the dense limestone has been transformed into marble, and on the other, typical contact minerals, such as garnet, vesuvianite, wollastonite, tremolite, bluish calcite and radial pyroxene, have been formed. A lime-silicate-hornstone is also often found, which may have originated from a marly limestone stratum.

These various formations are distinguished under the names "Lagerarten" (bed-matrices) or "Gangarten" (gangues), or "Scheidung" (partition), and at some points attain a thickness of 300 m. (south of Arpad mine, near Dognacska). For the most part they naturally occur at the contact of dacite and limestone, but they are also found between Archean schists and dacite and Archean schists and limestone. At any rate, the eruptive rock is always to be found near by; in fact, according to Vom Rath's observations, the entire region seems to be permeated by eruptive dikes and intrusions.

According to the microscopic investigation of Sjögren the *"garnet rock,"* the most common contact product, which to the eye appears composed exclusively of brown or yellowish-green, often finely crystallized garnet individuals, contains, besides the main ingredient just named, min-

Fig. 242.—Geological sketch-map of the Banat mineral district. (E. Suess.)

erals of the amphibole group, quartz, pistacite and calcite, all of which form a part of the rock. A majority of all the ore masses are associated with these contact beds, though orebodies in the pure limestone, or in the dacite directly at the contact, are not uncommon. All the occurrences are characterized by irregularity both in extent and in ore content. Often the entire contact zone appears finely impregnated and veined with ore. In other cases merely irregular nests occur, while elsewhere massive orebodies, the ore stocks, predominate. Lode-like masses, too, have been observed. The nature of the ores is not less varied than the mode of occurrence. In the western sedimentary zone it was mainly the copper ores that induced mining. They were as follows: Copper glance, bornite, gray copper, chalcopyrite and pyrite, also galena, zinc-blende, magnetite, and at a few isolated localities native gold, arsenopyrite, stibnite, molybdenite and cobalt pyrite.

All these mineral fields, which extended around the towns of New Moldava, Szaska, Csiklova and Oravicza, have a very ancient history. In Roman times they were flourishing, while at the present day they are nearly all idle. The only one that is still of importance is the iron ore deposit of Dognacska and Moravicza, which is connected with the smaller limestone zone situated east of the main mountain range. This iron-mining industry, which produces magnetite, together with red and brown hematite, has been a prominent producer since the beginning of the 18th century. In 1890 the production was about 1,000,000 tons, most of which is consumed by the Reschitza furnaces. In former times, Dognacska was also known as a copper deposit, and even to-day copper, lead and zinc ores occasionally accompany the iron ores, without, however, being of any importance.

It is interesting to note that these ores, particularly those of the copper mines, usually held a small amount of gold; also that the dacite occasionally (for example, at Moravicza) is traversed by true gold quartz veins, which carry pyrite in the quartzose gangue, and possess the unusual peculiarity of carrying fine sprinklings of magnetite (see Marka, page 339).

A brief description of the various mine fields from the south end northward is added.

New Moldova.—This is probably a very old mining field, for here, not far from the Roman station of Versecia, were the "hundred shafts" (*centum putea*) mentioned by Tacitus. Irregular, branching intrusions of dacite occur along the boundary between Cretaceous limestone and mica schist and give rise to contact formations. Besides garnet rocks, this region seems to be characterized by the presence of silicates in the altered calcareous strata. Before 1860 copper ore alone was mined. The ores then

found were mainly copper glance, bornite, chalcopyrite and the salts derived from the alteration of these sulphides. Native copper, too, is said to have occurred quite frequently. Later on the mining was mainly confined to pyrite, which accompanies the ore in great masses. Two vast pyrite masses, the Johann-Evangelista and the Fridolin pyrite stocks, both situated at the contact of garnet rock and dacite, are of especial importance. The pyrite was mined solely for the manufacture of sulphuric acid.

It is interesting to note that to the south of the Benedikter Gebirge, where lead ores were formerly mined, they were associated with a hornstone containing octahedrons of fluorspar in numerous quartz druses (see von Cotta, p. 48).

Szaska lies close to the west boundary of the western sedimentary ranges. The dacite outcrop is 9 to 10 km. (5.4 to 6 miles) long and averages 100 to 400 m. (328 to 1,312 ft.) wide, and sends out innumerable branches and smaller massives (see Vom Rath, p. 48). The contact formations are less extensive, but in other respects correspond closely to those of New Moldova. In the northern part of this district copper ores, mostly rich, occurred, and tremolite seems to have been a predominant gangue (see Castel, p. 441). The most important mine is "Ritter St. Georg," in which the ores, mainly copper pyrite and pyrite, occur in irregularly shaped and irregularly distributed nests, which, as a whole, represent a zone parallel to the contact (see von Cotta, Fig. 12, p. 53). To the south of this area, at the villages called Maria Schnee and Kohldorf, the iron ores predominate by far over the copper ores, occurring partly as oxides, partly as sulphides.

Oravicza-Csiklova lies about 18 km. (11 miles) north of Szaska. At this place the contact rocks are the main carriers of the ore, though compact orebodies are found but rarely, the ores being distributed in fine veinlets through a well-defined zone of the contact rock, which thus constitutes the so-called stockwork. Other more compact orebodies, the so-called Butzenwerke (Butzen, cone or lump), were merely of subordinate importance. According to Marka (see p. 313), contacts of different rocks seem to be accompanied by correspondingly different kinds of ores. Thus at the contact of dacite and limestone the ores were mainly pyrite and copper pyrite; at the contact of syenite and hornstones they were copper pyrite, arsenopyrite and tetrahedrite, while between dacite and mica schist ore was but rarely observed. The richest ore masses occur where the contact is with garnet rock or limestone, copper pyrite, gray copper, arsenopyrite, zinc-blende, galena and pyrite being present. The most important mines were the Baron and Speis shafts at Csiklova (see von Cotta, Fig. 13). Small ore-bearing fissures found in the dacite and carrying copper

pyrite and pyrite must be regarded as true veins. Where they cross one another, orebodies occur that are rich enough to work.

A very remarkable gold deposit is situated somewhat to the north of Oravicza, but, like all the mines just described, it is at present unworked. A funnel-shaped mass, triangular in outline and about 180 m. in diameter at the bottom of the drift, is bounded by bluish calcareous marl, garnet rock and mica schist. The entire space is filled with a clayey, occasionally sandy mass, in which are imbedded fragments of limestone, garnet rock and mica schist, as well as a granite-like rock (probably a modification of dacite, since Marka mentions intrusions of "syenite"). Both in the clay filling and in minute fissures in the fragments free gold occurs, in the form of delicate scales or granules, more rarely as wire gold. The accompanying ore minerals are pyrite, chalcopyrite, tetrahedrite, bismuthinite and smaltite. The two last-named minerals are regarded as favorable for gold (see Marka, p. 455). There is, according to the descriptions, a friction breccia which appears to be the product of a movement occurring after the metamorphosis of the limestone. Subsequent intrusions of a dacitic (?) magma have penetrated into this breccia. That the dacite may be a carrier of gold is proved by the gold quartz lodes in the dacite near Moravicza, already noted.

Moravicza-Dognacsky.—As already mentioned, the mines near these towns are the only ones now being worked. The magnetite deposit is associated with a zone of Cretaceous limestone east of the main area of the Banat Range (after Halavats). The limestone forms a closely and narrowly compressed syncline in the Archean schists (mica schist, phyllite, granulite and quartzite), extending from Ezeres on the north to Kalina on the south, a distance of 17 km. There are but two breaks in the continuity of the rocks, whose outcrop varies from 30 to 100 m. in width. This strip of limestone is intersected at an acute angle by a large eruptive mass, striking northwest, so that there is a contact between the two rocks for a great distance. For this reason part of the limestone syncline is surrounded by a mantle of contact formations, in such way that these either occur between limestone and dacite or else between limestone and mica schist (see cross-section, Fig. 243). The deepest part of this limestone trough has been reached at different depths in the various mines, so that there can be no doubt of the nature of the structure (see Marka, table of profiles). The contact zone has a thickness of 20 to 300 m. (65 to 984 ft.) and consists mainly of garnet rock, but tremolite and a black, radial pyroxene also occur, as well as the secondary minerals derived from various contact products, such as serpentine, allophane, schweizerite, chlorite, etc. In these congenial beds the magnetite is either distributed irreg-

ularly or occurs as massive, stock-like orebodies, up to 150,000 tons in weight. Under the microscope, garnet and magnetite seem to be of simultaneous origin, as is indicated also by a platy intergrowth of garnet and magnetite (the so-called band ore).

Copper ores were formerly obtained from the Dognacska region, though at the present day the iron ores, magnetite, hematite and limonite are alone of economic importance. The following minerals occur: Galena and its alteration products, bornite, tetrahedrite, blende, pyrolusite, pyrite, gold—in brief, all the ores which we found to be of importance in the other deposit. A further fact of interest in the present connection is the presence of veins and stringers of magnetite in granular limestone, observed by Vom Rath in the Arpad mine (see Vom Rath, p. 47), an occurrence which appears to be as remarkable as the above mentioned gold quartz lodes in dacite at Moravicza, which contain magnetite

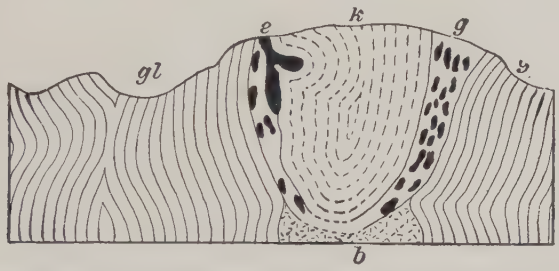


Fig. 243.—Cross-section of the limestone syncline of Moravicza at the Paulus mine; from local surveys.

gl, mica schist; k, crystalline limestone; b, banatite; e, magnetite; g, garnet rock.

finely interspersed. (Compare the magnetite stringers in limestone at Pitkäranta, p. 440.)

A close analogy exists between certain deposits in the Banat and those of Rodna, in the head-water area of the Szamos, in Transylvania, which have been described in detail by F. Posepny and others.[1]

[1] The most important publications (since 1863) on the ore deposits of the Banat: B. v. Cotta: 'Erzlagerstätten im Banat und Serbien,' 1864. G. Marka: 'Einige Notizen über das Banater Gebirge,' *Jahrb.* d. k. k. geol. Reichsanst., 1869, p. 312 *et seq.* Joh. Kudernatsch: 'Geologie des Banater Gebirgszuges,' *Sitzungsber.* d. k. Ak. d. Wiss. in Vienna, 1857, Vol. XXII, pp. 39-148. Niedzwiedzki: 'Zur Kenntniss des Banater Eruptivgesteins,' Tschermak's *Mitt.* 1873, p. 255. G. vom Rath: 'Vorträge und Mittheilungen,' *Sitzungsber.* d. niederrhein. Gesellschaft f. Natur- und Heilkunde, Bonn, 1879, p. 38 *et seq.* H. Sjögren: 'Beiträge zur Kenntniss der Erzlagerstätten von Dognacska und Moravicza,' etc. *Jahrb.* d. k. k. geol. Reichsanst., 1866. v. Halaváts: *Jahrsber* d. k. ungar. geol. Anstalt, 1887, 1888, 1889, *et seq.* *Oesterr. Zeitschr.* f. B. u. H. Das Eisenerzgebiet von Dognacska und Moravicza im Banat, 1891, p. 91 *et seq.* *Geologische Spezialkarte* d. k. ungar. geol. Landesanstalt. 1: 75,000.

Literature on Rodna: F. Posepny: 'Ueber die Natur der Erzlagerstätte von Rodna,' *Verh.* d. k. k. geol. Reichsanst, 1870, p. 19. G. vom Rath: *Z.* d. D. G. G., 1878, Vol. XXX, p. 556.

5. *The Contact Deposits of the Christiania Region.*

The fact that the ore deposits in the vicinity of Drammen, near Christiania (consisting mainly of magnetite and hematite but showing considerable variety of mineralogic development), occur in the contact zone between Paleozoic rocks and granites, and in part occur at the very contact itself, was recognized many years ago by Keilhau,[1] and this has been confirmed by A. Daubrée and Th. Kjerulf.

According to J. H. L. Vogt, this group of deposits comprises at least a hundred and probably several hundred deposits, mostly rather small, "which must beyond question be regarded as contact products of the granites with the various pre-granitic rock members (basal complex, Silurian and porphyry sheets)." In support of this view, that author gives the following statistics. Among 104 accurately examined pits and prospects:

(I) 17 deposits are found within Silurian rocks enclosed by granite.

(II) 22 are found exactly at the boundary between granite and Silurian, or within 10 m. from the boundary, the ore being always enclosed in the Silurian strata.

(III) 48 are found in the Silurian contact zone, mostly 0.1 to 0.5 km., in some cases 1 to 1.5 km. from the granite boundary.

(IV) At most ten lode-like bodies occur in the gneiss.

(V) Many such veins occur in the augite-porphyrite near the granite boundary.

Most of these deposits are intercalated approximately parallel to the stratification of the slates and limestones. Many are cut by tongues of the granite intrusions and dikes of quartz porphyry (granophyre) and of various granites, proving that they were formed before the last phase of eruptive activity had closed. The country rock shows intense normal contact metamorphism, with the formation of new garnet, vesuvianite, scapolite, biotite, pyroxene, hornblende, epidote, chiastolite, etc. The ores, which have not only replaced limestone, but even more frequently slate, consist of the oxides of iron with subordinate amounts of copper pyrite, argentiferous galena, blende, iron pyrite, arsenopyrite, smaltite, bismuthinite and molybdenite. Calcspar, fluorspar, apatite, garnet, epidote, rarely also axinite and helvine, accompany the ores.

[1] B. M. Keilhau: 'Gaea Norvegica,' Christiania, 1838. Vol. I, pp. 61-69, 73-83, 107, 109, 125. A. Daubrée: 'Skandinaviens Erzlagerstätten,' Uebers. durch v. Leonhard, 1846, pp. 26-56. Th. Kjerulf: 'Ueber die Geologie des südlichen Norwegens,' Christiania, 1857. W. C. Brögger: 'Die silurischen Etagen 2 und 3 im Kristianiagebiet,' etc., Christiania, 1882. Also 'Die Eruptivgestein des Kristiana-Gebietes,' I-III, Vidensk. Selsk. Skr., Christiania, 1894, 1895, 1897, and 1898. J. H. L. Vogt: 'Dannelse of Jernmalm,' *Geol. Fören. Förh.*, 1891, Vol. XIII, p. 735 and 1892, Vol. XIV, p. 211. Résumé in German, pp. 243-245.

Thus even the iron deposits show examples characteristic of the tin deposits. It is worthy of note that the various facies (distinguished by W. C. Brögger) of the plutonic rocks of the region are not uniformly favorable for the development of ore deposits at their contact. The nepheline and augite syenites are bordered by very scanty deposits of sulphide ore. The three granitic members of the eruptive series, nordmarkite, soda granite and granitite, on the contrary, are surrounded by a border of ore deposits, while the diabase dikes which represent the closing act of volcanic activity are associated with merely local deposits of galena and zinc-blende with fluorspar.

Mining operations at all these contact deposits are at present either quite insignificant or entirely stopped.

6. *The Ore Deposits of Traversella and Brosso, Italy.*

Between Traversella and Brosso, in Piedmont, a diorite stock, probably of Tertiary age[1], is intruded in mica schists containing intercalations of crystalline dolomite. At Traversella[2] the limestone near the contact is in part altered into a fine-grained crystalline garnet-pyroxene rock with epidote, amphibole and traversellite; another part is replaced by ore. In the Montajeu and Gias de Gallo mines magnetite alone occurs, while in the Riondello mine near Traversella the ore is a mixture of magnetite with pyrite, the latter sometimes forming large masses of nearly pure chalcopyrite. The subordinate minerals include pyrrhotite, marcasite, arsenopyrite, galena, zinc-blende, stibnite, molybdenite and in rare instances scheelite and wolframite. The ores are accompanied by dolomitic spar, talc, steatite and chlorite, occasionally by calcspar, quartz and fluorspar.

On the other hand, at Brosso, on the middle slope of the lower Dora Baltea valley, beds of magnesian limestone are mineralized by hematite and pyrite. This ore has, by reason of a pre-existing system of fault fractures, penetrated a longer distance than usual from the contact. It has been found that, wherever such a fissure cuts through a limestone bed, an orebody has been formed whose thickness decreases with the distance from the contact. These compact orebodies attain a diameter of 20 m. (65 ft.) or more and have a uniform strike. They consist of pyrrhotite and magnetite, with occasionally a little pyrite. These fissures, which continue into the diorite, also contain orebodies, but none that pay for working. The

[1] V. Sclopis and A. Bonacossa: *Monogr.* sulle miniere di Brosso (circond. d'Ivrea). Torino, 1900.

[2] V. Novarese: 'L'origine de giac. metallif. di Brosso e Traversella in Piemonte,' *Boll.* del R. Com. geol. 1901; No. 1, gives list of previous publications. 'Die Erzlagerst. von Brosso und Traversella,' *Zeit. f. Prak. Geol.*, 1902, pp. 179-187.

ores contain gold-bearing pyrite, marcasite, arsenopyrite, galena, copper pyrite and rarely zinc-blende, stibnite and bournonite, in a matrix of quartz and spathic iron stone.

At present the deposit near Brosso is the only one worked. It is worked for pyrite, which is used in the manufacture of sulphuric acid, the mean annual production being 25,000 tons.

7. *The Iron Ore Deposits of the Island of Elba*[1].

The iron ores of Elba are found only along the east coast of the island. The total known extent of the field is estimated by A. Fabri at 2,000 hectares, the deposits near Cape Calamita covering 1,130 hectares.

The ores consist of specular hematite, or of ordinary red hematite with limonite and magnetite at some points. The deposits form either sheeted masses, unquestionably superimposed on older strata, or irregular replace-

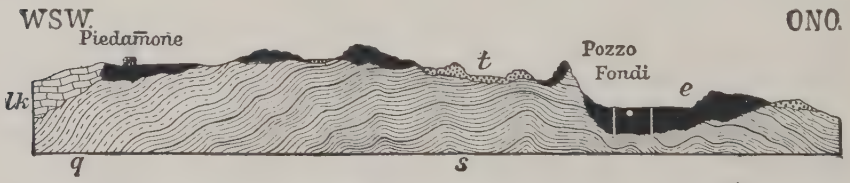


Fig. 244.—Section through the iron ore deposits of Rio. (Fabri.)
q, quartzite; s, sandstone and mica shale, of the Permian; lk, breccia-like limestone; e, iron ore; t, barren masses.

ments in the limestones, the latter deposits containing the minerals that elsewhere characterize contact metamorphic iron ore deposits.

The specular hematites at Rio Albano, Rio and Vigneria overlie Permian sandstones, quartzites and micaceous schists (Fig. 244), but are in turn overlain at some points by the limestone breccias of the Lower Lias. Sometimes, as at Pozzo Fondi, near Rio, the ores fill kettle-shaped depressions in the surface of the irregularly eroded Permian dolomites. Conversely, to the northwest of Rio the ores are seen to extend upward into the overlying calcareous breccias of Lower Liassic age, the upper limit being very irregular. It is probable that the depressions and hollows in the surface of the Permian now occupied by iron ore were originally filled by calcareous rocks. Finally, east of Rio Albano the Upper Liassic clay

[1] B. Lotti: 'Impressioni geol. di una breve gita all' isola d'Elba,' *Boll.* geol., 1876, Vol. VII. S. Czyszkowski: 'Régions ferrifères de l'île d'Elbe,' Alais, 1882. B. Lotti: 'Memorie descr. della carta geol. d'Italia' (Dell' Isola d'Elba), 1886, Cap. XIX, with full bibliography. B. Lotti: 'Sui depositi ferriferi dell' Elba,' etc., *Rass. Min.*, 1901, Vol. XIV, 4. A. Fabri: 'Relazione sulle miniere di ferro dell' isola d'Elba,' Roma, 1887.

slates are permeated by innumerable small veins of specular hematite. It is noteworthy that the iron ores of this region do not contain the admixtures of lime silicates characteristic of the southern fields. However, in the vicinity of the ore deposits, near Torre di Rio, there is an occurrence of pyroxene and epidote as a replacement deposit in a pre-Silurian calcareous slate.

A different state of affairs is found at Terranera, where the ore, mainly specular hematite, fills the bottom of a small valley cut in a series of Silurian shales with calcareous intercalations. At Capobianco limonite and manganite fill depressions in a micaceous gneissoid schist, traversed by many granite dikes, and the orebody has branches running downward. On the coast near Capobianco a mass of tourmaline granite outcrops, and granitic dikes near Terranera show that there, too, plutonic masses may lie beneath the earth's surface.

Fig. 245.—Section through the iron ore deposits of Calamita. (Fabri.)
dk, crystalline dolomite; e, iron ore; kes, lime-iron-silicate rock.

Finally, in the Calamita area the iron occurs as hematite, limonite and magnetite, always accompanied by light-colored radial pyroxone, ilvaite (a hydrated calcium-iron silicate) and epidote, as well as garnet, opal and resinite (wax opal). Both the iron ores and the complex mixture of these other minerals are in every instance closely associated with crystalline dolomitic limestones, intercalated in mica schists and gneissoid schists of pre-Silurian age. The connection between iron ore, lime silicates and this limestone is shown in the section, Fig. 245. These facts leave no doubt that the limestone has been replaced by the ore and its accompaniments, a conclusion confirmed by the residual remnants of limestone lying in the midst of the mass of lime-silicate. Similar remarks apply to the deposits of Ginevro and Sassi Neri.

The similarity of the iron ore deposits of Elba to those of the Banat is so great that they, too, may be assumed to be genetically connected with deep-seated siliceous, igneous rocks. A direct contact with granitic rocks, to which the mineralization might be attributed, is, however, not shown at

Elba, as it is in the Banat region. It is surmised, however, that in the Elba iron district such plutonic masses may have initiated uprising mineral-bearing solutions, which not only mineralized the limestones, but also penetrated along the joints of non-calcareous strata. It can hardly be supposed that the solutions deposited their burden on the earth's surface, as might appear at first sight. As the tourmaline granite of Elba is intermediate in age between Eocene and Miocene it is reasonable to suppose that the iron ores, too, are of the same late period.

The technical value of the Elba iron ores varies greatly. On an average the ores contain the following percentages of iron: Rio Vigneria and Rio Albano, 60 to 66%; Terranera, 62 to 68%; Capobianco, 50%; Calamita, 54 to 63%; Ginevro, 60 to 63%.

The Capobianco ore also contains an average of 6% of manganese. The Elba iron ores are practically free from phosphorus, sulphur and copper. Only at two points do the ores contain an amount of phosphorus worth mentioning. Iron pyrite seldom forms a disturbing factor, and if copper ores occur, as at Calamita, they are easily picked out.

The wealth of Elba in iron ore was known in classical antiquity. Virgil, for example, mentions it in the Æneid. From the 11th century onward, detailed data containing the mining industry of the region are preserved. The mines belonged in succession to the republic of Pisa, the Prince of Piombino, France, Napoleon I, the Grand Duchy of Tuscany and finally, since 1881, to the Kingdom of Italy. Since 1880 the annual production of the iron mines is limited to 200,000 tons, although, according to Fabri's estimate in 1884, the stock then remaining amounted to 7,990,000 tons, so that it cannot be exhausted for a long time. In recent time, furnaces have been established on Elba itself.

8. *The Iron Ore Deposits of the Gora Magnitnaia.*

The Magnitnaia Mountains, which in the Atatsch rise to a height of 577 m. (1,890 ft.), are situated near the Ural river 65 km. (39 miles) south of Verhne Uralsk, on the low plateau which gradually passes into the flat Kirghese plain. The main mountain mass, according to J. Morozewicz,[1] consists of eruptive rocks of very diverse types. In general, augitic and amphibolic granites and diorites are intruded by younger syenites and augite-orthoclase-porphyries. These two groups are in turn intruded by dikes of quartz keratophyr and a cordierite-sillimanite-vitrophyre (atatschite). The augite feldspar rocks, usually much decomposed, are

[1] J. Morozewicz: 'Le Mont Magnitnaia et ses alentours,' *Mémoirs* du Comité Géologique, 1901, Vol. XVIII, No. 1, pp. 74-104; in Russian, with French résumé.

overlain on the lower mountain slopes by large and thick blocks of garnet rock, overlain in turn by deposits of magnetite, hematite and limonite, which altogether cover an area of about 2 square kilometers and attain a thickness of over 80 m. (262 ft.) The iron ore forms pockets, stocks and lump-shaped beds. It contains disseminated quartz and calcite, besides garnet, and the ore often alternates quite irregularly with a garnet epidote rock or with kaolinized masses. Besides the garnet rock, marble is found here and there, but normal Lower Carboniferous limestones are found only far away in the environs of the mountains and concealed by Pleistocene deposits. These structural and geological conditions resemble those in the Banat iron deposits so closely that those of Magnitnaia are placed next to the Banat in this work. Morozewicz, however, does not claim a contact metamorphic genesis, but on the contrary tries to prove a purely hydrochemic origin. According to him the weathering of the eruptive rocks altered the augite to garnet, which in turn on further decomposition gave epidote, chlorite, magnetite, hematite, quartz and calcite. It is well known, however, that the usual process of weathering of such eruptive rocks does not take place in this way. Moreover, the garnet rocks and ore masses are far too extensively developed to be explainable as the result of merely superficial weathering.

9. *The Copper Deposits of Miednorudiansk, Near Nizhnyi Tagilsk.*

Although the geology of this ore deposit, formerly famous for its great wealth, is as yet not known in detail, all the existing descriptions[1] show that the copper deposits are the result of a concentration effected mainly by metasomatic processes in the contact region about plutonic masses.

Miednorudiansk lies immediately south of the Vysokaya Gora (central Ural), whose magnetic iron ores contain interspersed copper sulphides, as mentioned previously. The copper deposits lie between two belts of fossiliferous Devonian limestone, in a rock mass formed of brecciated calcareous porphyrite-diabase tuffs and much altered green schists having north-northwest trend. A zone of limonite and ferruginous clay extends the entire length of the range. This belt has yielded great quantities of oxidic copper

[1] P. Jéréméew: 'Observations sur les gîtes cuprifères du versant et de la chaine de l'Oural,' in Russian, *Journ.* d. mines, 1859, Vol. IV, p. 76. H. Müller: '(Vortrag im bergm. Verein zu Freiberg.)' *Berg. u. Hütten Zeit.*, 1866, No. 22. Gr. Mayer: 'Ueber die Kupfererzlagerstätte Mednorudjansk am Ural,' *Oesterr. Z.*, 1877, No. 36, 37. A. Karpinsky: 'Aperçu des richesses minér. de la Russie d'Europe,' 1878. P. Gladki: 'Chemische-geol. Bemerkungen über die Erzlagerstätten Mednorudjansk und Wyssokaja Gora' (in Russian), *Journ.* d. mines, 1888, Vol. I, pp. 96-123. Th. Tschernyschew: *Guide* du 7th Congrès Géol. Intern., 1897, Vol. IX, p. 11. E. S. Fedorow: 'Ueber Mednorudjansk,' *Mitth.* des Verbandes der russ. Berging (in Russian), St. Petersburg, 1900.

ore and in depth contains copper pyrite, bornite and copper glance. Besides the malachite, for which the mine is famous, the iron-charged clays also contained azurite, tagilite, asperolite, brochantite, libethenite, chrysocolla, demidowite, melaconite, cuprite, native copper, etc. The greatest accumulations of ore were found where the clayey masses were in contact with the limestones. The latter in many cases appeared corroded into a spongy mass, which sometimes carried fossils that were readily detachable. In the northern part of the mineralized area, at the Avrorinsky shaft and in the Svernaya shafts, bodies of magnetic iron ore containing copper ores disseminated through the mass are found at the contact of the western limestone zone. This combination of magnetic iron ore with copper sulphides, together with the widespread occurrence of partly epidotized pyroxene garnet rock in the Miednorudiansk mines, suggests that these ore concentrations are within an eruptive contact zone.

Formerly H. Müller[1] thought that a copper-bearing diorite rock existed in depth, which by its decomposition had furnished the iron-charged clays with the copper oxides. Hence he described the deposit as analogous to that of Gumeshevsk (see page 601). This, however, does not seem to have been confirmed by later studies.

E. S. Fedorow[2] has recently shown the almost complete absence of a primary eruptive feldspathic rock. It is, however, possible that at still greater depth there are the syenites and orthoclase porphyries of the neighboring Vysokaya, which form the real generators of ore. This seems to be indicated by the dike of what is presumably augite porphyry, recorded by the last named author.

The Miednorudiansk mine has yielded most of the malachite worked up into objects of art in the Imperial stone-polishing works, one huge block weighing 328 tons being found in 1836 at a depth of 70 to 80 m. The ores at this mine average 2.3%, with an annual production of 1,240 tons of copper (DeLaunay). From 1814 to 1877, 2,600,000 tons of ore were produced.

The Bogoslavsk copper mines, situated much further north, on the east side of the mountains, exhibit quite similar geologic conditions, as shown by Müller, E. S. Fedorow and recently by Usspenski[3], who shows that the orebodies are intimately associated with the augite-garnet rocks found where Lower Devonian limestones are cut by hornblende granite and porphyries. Later porphyry dikes cut and displace the orebodies.

[1] H. Müller: *Berg u. Hütten. Zeit.*, 1866, p. 160.

[2] E. S. Fedorow and W. W. Nikitin: 'Das Bergrevier von Bogoslowsk,' St. Petersburg, 1901. With many plates, sections, etc., and bibliography (in Russian).

[3] Usspenski H: 'Die Eisenerzlagerstätten im Bergbezirk Bogoslowsk,' *Berg Journal*, IV., St. Petersburg, Nov., 1900, in Russian.

10. *The Copper Ore Deposits of Gumeshevsk.*

Gumeshevsk lies seven and a half miles southwest of Ekaterinburg, on the west slope of the Ural. According to H. Müller[1] a belt of marmorized limestone, intercalated between crystalline schists, is cut lengthwise by a dike of diorite, dipping from 40 to 50° east, and having a thickness of 50 to 60 m. (164 to 196 ft.) At the contacts on each side there are ocher yellow, iron-charged clays, the products of subsequent decomposition of the rocks. This clay occasionally reaches a thickness of 200 m. (650 ft.) in outcrop, but wedges out below. Moreover, the garnet rocks seem to belong to the contact. The ores are found partly in nests of iron pyrite and copper pyrite in the diorite of the lower portions of the deposit, but mainly in the earthy clays as malachite, chrysocolla, cuprite, azurite, earthy red oxide of copper, and brochantite. A malachite block weighing 2,800 kilograms was found in this deposit at a depth of 36 m. below the surface, a part of it being now in the museum of the Mining Institute at St. Petersburg. The ores mined contained on an average 3% to 4% copper. The mines are now abandoned. Quite similar conditions prevail, according to H. Müller, in the deposits of Soimonovsk, five miles southwest of Kyschtim.

11. *The Copper and Lead Ore Deposits in the Campiglia Marittima, Italy*[2].

In the Campiglia Marittima, in the coastal plain of Tuscany, 35 miles southeast of Leghorn, a metamorphic marble (Lower Liassic) is cut by peculiar eruptive dikes which are regarded by some authors as quartz porphyry, by others as liparite, the rocks occurring in part in the form of mixed dikes. The latter feature is characteristic of the Temperino dike, which holds an important ore deposit. This dike has a north-northwest strike, and runs southwest of Monte Calvia, which overtops the region.

The Temperino vein, attaining a thickness of 20 m. (65 ft.), as exposed in the Cava Grande and some other mines, consists, near the point first mentioned, mainly of a cordierite bearing liparite, or quartz porphyry. In

[1] H. Müller: 'Kupfererzlagerstätten von Gumeschewsk und Soimonowsk am Ural,' *Berg u. Hutten. Zeit.*, 1866, No. 29, p. 252.

[2] P. Savi: 'Abbozo de carta geologica de provincia Pisana,' 1863. F. Hoffmann: 'Geogn. Beobachtungen auf einer Reise durch Italien und Sicilien,' Karsten's Archiv, Vol. XIII, pp. 24-29. A. Burat: 'Théorie des gîtes métallifères,' etc. Paris, 1845, p. 208. G. vom Rath: 'Geognostisch-mineralogische Fragmente aus Italien,' II, part No. 7. 'Die Berge der Campiglia in der Toskanischen Maremne,' Z. d. D. G. G., 1868, Vol. XX, p. 307 *et seq.* B. Lotti: 'Le roccie eruttive feldspatiche di Campiglia Marittima,' *Boll.* del R. Comit. Geologico, 1887, Nos. 1 and 2. Also 'Sulla Genesi dei giacimenti, etc.,' *Boll.* geol. 1900, No. 4, with bibliography.

the middle it is much more basic and may be described as an augite porphyry showing rather sharp boundaries against the quartz porphyry on both sides. At other points, as in the Coquand shaft, one band of quartz porphyry is lacking, and thus the cross-section loses its symmetry. In all cases, however, a very remarkable mass of ore-bearing rock is found at the contact of this mixed vein and the Liassic limestone, which is there completely crystalline. The ore-bearing mass consists of a radiating, dark green iron-lime-manganese augite and a greenish-gray or reddish manganese lime augite, as well as ilvaite (a lievrite). The augite occurs in radial fibers forming round masses and is permeated by black ilvaite. The ores are intimately connected with these silicates, and consist most frequently of chalcopyrite, iron pyrite or less commonly of galena and brown zinc-blende, together with some arsenopyrite, all of which are sometimes accompanied by quartz and calcspar. The ores appear either as cores of the spherical augite concretions or lie between the radiating needles of augite. Stringers of the ore-bearing augite mass branch off toward the adjoining marble. According to Bergeat[1] fluorite also occurs.

Northeast of the Temperino vein, in the direction of Monte Calvi, there is a parallel vein of similar composition which has been worked in the Cava del Piombo and some other mines. In the Cava del Piombo, east of Castello San Silvestro, it is about 20 m. thick. Its ore-bearing part consists of radial augite spheroids up to 2.4 m. in diameter, which contain cores of the above named metallic sulphides. Moreover, from this nucleus of ore radiating stringers of ore extend outward and sometimes the augite spheres are encrusted by thin layers of ore. The spaces between the augite nodules are filled with an irregular, granular-fibrous mass of augite with large quartz druses.

The genesis of these deposits is as yet quite a puzzle. As, however, the peculiar radial augite aggregates seem to have been formed as a sequel to a contact action between an eruptive magma and Liassic limestone, and as the ores evidently represent segregations formed simultaneously with the augite, the deposit has been placed in the class of contact metamorphic deposits. It seems, however, to correspond more closely in its genesis to that of the tourmalinized and auriferous rocks of and about several granite areas.

Copper and lead mining in the Campiglia Marittima seems to date back to Etruscan times. The mines were actively worked in the days of the Medici, and were reopened on the two veins about the beginning of the 19th century.

[1] 'Beiträge zur Kenntniss der Erzlagerstätten von Campiglia Marittima,' N. J. f. M., 1901, part I, p. 135.

12. *The Silver Lead Deposits of Sala, in Sweden*[1].

The mines lie 2.5 kilometers southwest of Sala, in Westmanland. While the town itself is built on a flat cultivated plain, the ground of the mining region rises in low, often rocky hills. An area 10 km. long and up to 3.6 km. wide is covered by a granular crystalline, dolomitic limestone, striking northnortheast-southsouthwest, abutting on the west against fine-grained flaky biotite gneisses and 'hälleflinta,' while on the east it is cut off by hornblende granite. In one of the limestone quarries the rock is seen to be traversed by a diabase dike 0.36 m. thick, several times faulted, and this feature has been repeatedly encountered in the mines. The most striking feature about these mines is the great cave-in, formed in olden times by the collapse of extensive excavations. On the bottom of this basin the work has been resumed, the deposit being worked at the present time for zinc-blende, whereas formerly only the argentiferous galena

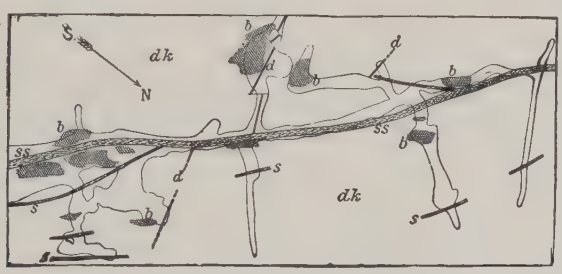


Fig. 246.—Plan of the 190 m. level of the Sala Mine.
dt, dolomitic limestone; s, skolar; ss, stor sköl; d, diabase; b, galena.

was extracted. On one of the walls of this cave-in, the Stor Sköl (literally, large shell, meaning main fissure) is at present well exposed, consisting of a zone of friction breccia 3.5 m. thick, which passes through the dolomite limestone with a dip of 60° west. This Sköl consists of completely crushed country rock, traversed by slip planes and permeated by stringers of calc-spar, chlorite and talc segregations, and also carrying layers of zinc-blende that lie parallel to the walls.

Further information is afforded by the underground workings (all in the limestone), which lie on both sides of the Stor Sköl, and show it to run nearly south, and to be usually 1 to 3 m., rarely as much as 10 m. wide.

[1] Important publications: W. Hisinger: 'Versuch einer mineralogischen Geographie von Schweden,' Translation by F. Wöhler, 1826, pp. 124-133. B. v. Cotta: 'Lagerstätten II,' 1861, p. 528. O. Gumaelius: 'Sveriges Geol. Undersökn,' Bladet Sala, 1868. Also 'Om trappsköIen i Sala grufva,' *Geol. Fören Förh.*, I, 1872-1874, pp. 162-166. Fuchs and De Launay: 'Traité,' 1892, Vol. II, p. 611.

In the course of many years of mining the work has exposed numerous narrow side fissures, spurs from the main fissure, as well as a number of parallel fractures, whose arrangement may be gathered from the ground plan of a part of the 190 m. level shown in Fig. 246. This also shows how the diabase dike above mentioned is displaced by the Stor Sköl.

Only a small amount of ore is found within the skölar, and this is seldom workable. On the contrary the ore occurs mainly as impregnations and as a network of stringers in the midst of the dolomitic limestone near the skölar, as is also shown in Fig. 246. The richest orebodies have been worked along the Stor Sköl. Their boundaries are naturally not sharp, the ore-bearing rock passing quite gradually into barren limestone. The orebodies are frequently separated from the Sköl by a barren, or at any rate a very poor zone lying between the Sköl and the exploited masses.

The main ore minerals at Salberg are argentiferous galena and brown or yellow zinc-blende. The two as a rule are not commingled, but occur in separate orebodies. Toward the west the zinc-blende predominates. The lead ore contains 3% to 4% lead, which in turn contains 0.70% silver (Fuchs and De Launay). Associated with these two ores are also found iron pyrite, arsenopyrite, stibnite, rarely also copper pyrite and two varieties of silver amalgam with 50% and 75% silver respectively. According to Hj. Sjögren, a part of the silver is present as silver glance. Sometimes the galena is intimately intermingled with magnetite. This rare association becomes more intelligible when it is remembered that, besides the orebodies of the Salberg mine, the crystalline limestone contains large beds of magnetic iron ore, which have in fact been worked. Among the still rarer ore minerals at Salberg, mention must be made of pyrrhotite, native silver, ruby silver, tetrahedrite, native antimony, boulangerite and cinnabar.

Furthermore, the crystalline dolomitic limestone in the vicinity of the orebodies often contains various silicates, sometimes constituting entire beds with schistose structure, in which case they may also be impregnated with ore. Among these silicates, the most frequent are talc, chlorite, serpentine, actinolite, and melacolite. Broken crystals of salite, recemented by galena, have been found and a blackish garnet, a potassium feldspar and a heavy tourmaline occur rarely in the mixture. Spherical radial aggregates of black or bluish translucent tourmaline formerly occurred there, together with fibers of salite, in the midst of coarsely crystalline calcspar. Barite, too, is mentioned.

Hisinger long ago recognized that the Salberg deposits are impregnations of the limestone by material which has come from the Skölar. The presence of the garnet, salite and tourmaline suggests contact metamorphism of

the limestone by the neighboring granite, and there is a further probability that the mineralization of the limestone, too, proceeded from the Skölar, simultaneously with this contact metamorphism.

According to existing records, which date back to 1512, the mines of Sala were already worked during the reign of Sten Sture. According to tradition, however, the government mined for silver ore at a much earlier date, mainly during the reign of Magnus Ladulås (1249-1290).

The works were especially productive at the time of Gustavus Adolphus. From 1500 to 1800 the mines yielded a total profit of 1,600,000 Swedish marks, from 1800 to 1868 about 200,000 marks.

13. *Gold-Bearing Contact Metamorphic Deposits in Montana.*

A monograph by W. H. Weed[1] describes a very peculiar contact-metamorphic deposit in the Elkhorn region, Montana. This lies about 20 miles northeast of Butte (see page 223) on the eastern border of a great mass of granite, the Boulder Batholith, which is of Tertiary age. The ores occur in upturned and steeply dipping Paleozoic strata.

Of the many lesser properties, the Dolcoath is the most interesting. The ore deposit of the Dolcoath mine is a granular crystalline bed of garnet, diopside and calcite, which contains auriferous tetradymite and bismuthinite, as well as free gold.

On the higher slopes of Elkhorn peak, great masses of marble ¼ mile long and 100 feet thick occur included in the midst of andesite. The lower layers of this marble are composed of granular, garnetiferous magnetites.

As a supplement to the deposits described on page 539, mention may also be made here of an ore deposit of former economic importance, that of the Elkhorn mine proper, which is instructive in many respects. The orebody of this mine is of irregular shape and composed mainly of argentiferous and auriferous pyrite-blende lead ores. There are two classes of ores. The first is quartz carrying rich silver sulphides and a little pyrite. This dry ore is found along the shale-limestone contact. The second variety of ore consists mainly of argentiferous galena, argentiferous, light-colored, brown and blackish blende and pyrite. The orebodies form two rich shoots beneath an arch of altered shale, either along its contact with the crystallized dolomite, or as great stocks of silver-lead ore enclosed in the dolomite. These orebodies are situated in the crushed dolomite forming the saddle of anticlinal folds. The anticlinal 'saddles,' which in part have been broken up into a breccia, lie beneath a rather impervious cover of altered shale

[1] W. H. Weed: 'Elkhorn Mining District,' 22d *Ann. Rep.* U. S. Geol. Survey, Washington, 1902.

(hornfels), which is also folded. The crushed rock served as a channel for solutions rising from the depths, the axis of the folds having an oblique inclination. Thus the Elkhorn mine is a good example of the influence of folding on the development of metasomatic ore deposits. The mine just named showed from 1875 to 1899 the splendid production of 264,350 kilograms (8,902,000 oz.) of silver and 264 kilograms (8,500 oz.) of gold.

A large number of contact-metamorphic deposits of North America, in part carrying gold and silver ores, are adequately described by Lindgren[1] and Weed.[2]

The Bannock, Mont., example, with gold and gold tellurides in garnet rocks, has already been noted (p. 578).

14. *Contact Deposits of Asia and America.*

At Balia Maden, in Asia Minor, about 160 km. north of Smyrna, ore deposits[3] of considerable size are found at the contact between Carboniferous limestone and augite andesite. Along the contact in a zone 2 to 4 m. broad, the andesite is impregnated with quartz and ore, while the limestone, which contains epidote, garnet, anorthite and quartz, and is of superior hardness, encloses a number of irregularly columnar orebodies. These consist of argentiferous galena, together with zinc-blende, pyrite, copper pyrite and tennantite, also smithsonite and cerussite. They are closely connected with fissures running approximately parallel to the contact plane.

These mines, whose history extends back to the time of Pericles, have in recent times produced about 3,000 tons of lead annually. This contains 0.18% of silver, which is extracted locally. There is also an annual exportation of 7,000 tons of ore with 70% lead and 0.13% silver, as well as 4,000 tons of blende, some 100 tons of cadmia and a little copper ore.

At Tres Puntas, in the province of Atacama, Chile, the Mesozoic limestone has been changed, near intrusions of quartz porphyries or liparites, into a garnet rock containing copper ores. Similarly, at the Cerro de Campana in the province of Valparaiso, the Mesozoic limestone is altered at the contact with diorite and contains garnet with bornite and free gold (W. Moricke). The Seven Devils copper deposits of Idaho are similar (W.

[1] W. Lindgren: 'The Character and Genesis of Certain Contact Deposits.' *Trans.* Am. Inst. Min. Eng., February, 1901.

[2] 'Ore Deposits near Igneous Contacts.' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Bukowski: 'Die geol. Verhältnisse der Umgebung von Balia Maden.' *Sitzungsber.* d. K. Ak. d. W. in Vienna, math.-phys. class, Vol. CI, part I, February, 1892. K. Weiss: 'Lagerstätten im westlichen Anatolien.' *Zeit. f. Prak. Geol.*, 1901, No. 7. G. Berg: 'Beiträge zur K. von Balia-Maden.' *Zeit. f. Prak. Geol.*, 1901, p. 365. A. Κορδελλα. 'Ο μεταλλεύτικος πλοῦτος τῆς 'Ελλάδος. 'Εν' Αθήναις, 1892, Σ 64.

Lindgren[1]). Such deposits are common in Mexico[2], and extensive ore-bodies of this character are found accompanying deposits of another type at Clifton and Globe, Arizona.

In Queensland, according to G. Wolff[3], limestones at the contact with granite contain gold-copper ores, garnet, wollastonite and quartz.

The important deposits of iron ore found in the Tayeh district on Yangtse river in China, too, seem to be typical contact formations. According to G. Leinung[4], they occur at the boundary between sedimentary limestone and a diorite massif over a distance of about 15 km. with an average thickness of 75 m. They consist of hematite, red hematite, and magnetite, almost without gangue, and are on the whole poor in phosphoric acid.

D. ORE-FILLED CAVITIES IN ROCKS.

1. *Nodular Iron Ore.*

In several of the limestone ranges of central Europe, such as the Southern Black Forest, the Franconian Jura, the Alps of Tyrol, Carinthia and Carniola, and the Swiss and French Jura, the rocks show irregular chambers and enlarged fissures, which extend downward to a moderate depth. These spaces have the shape of irregular and often branching funnels, kettleholes, pipes or tubes, and contain hematite nodules enveloped in clay. These corrosion cavities occur mainly in the limestone and dolomite of the Jura, but sometimes in Triassic and Cretaceous limestone. The cavity walls have been etched smooth by the water and often appear as if varnished, especially when somewhat silicified. Sometimes they are also coated with a crust of brown hematite. When prongs occur some of them may be empty. The filling of the cavities is exceedingly varied. It consists mainly of limestone débris with red earth or clay, such as is so apt to be left as a residue from the solution of limestone. Besides this clay we find, together with the iron ore, various kinds of drift material, sand and clay washed in from above, and even streaks of lignite.

The age of this alluvial material may be determined by the organic remains frequently found with the ore. Teeth and bones of Oligocene mammals, such as anoplotherium, palæotherium and lophiodon and others of Miocene age, such as mastodon, rhinoceros and dinotherium, and Tertiary

[1] W. Lindgren: 'Character and Genesis of Certain Contact Deposits,' *Trans.* Am. Inst. Min. Eng., 1901.

[2] Aguilera: 'Geographical and Geological Distribution of the Mineral Deposits of Mexico,' *Trans.* Am. Inst. Min. Eng., Mexican volume, 1903. See also W. H. Weed: 'Ore Deposits near Igneous Rocks,' *Trans.* Am. Inst. Min. Eng., 1903.

[3] G. Wolff: 'Das Australische Gold,' *Zeit.* d. D. G. Ges., 1877, p. 149.

[4] G. Leinung: 'Bericht über das Eisenerzvorkommen im Tayeh-Bezirk, Provinz Hupeh.' Siegen, 1896.

plant remains are found, so that the introduction of the ore must certainly have taken place in the Tertiary.

Where such cavities occur in a basin of a limestone area, their filling is sometimes directly connected with superficial ore deposits of the same age. The latter are often of considerable thickness, as much as 30 meters (98 ft.). Most ores of this kind are considered to be deposits from iron-bearing springs and the hematite nodules in particular are regarded as concretions formed from such spring waters. This hypothesis may be

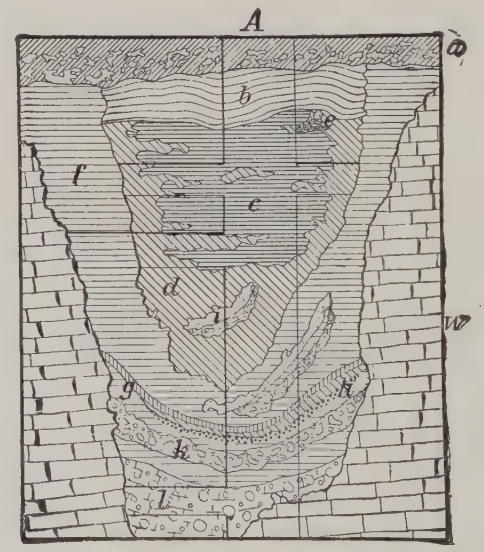


Fig. 247.—Section of a low-grade pocket of nodular ore. Ludwigsthal. (J. von Mandelsloh.)
a, Fragments of Jura limestone; b, blue and brown clay; c, lignite; d, clay with plant remains; e, chalky limestone masses; f, yellow clay; g, brown clay with lignite; h, bean ore; i, sandstone; k, quartz conglomerate; l, limestone conglomerate; w, limestone and dolomite of white Jura.

true in most cases, but not in all. As proved by Stelzner[1], the nodules of pisolite ores of the Villacher Alpe in Carinthia show no indication of a radial or concentric shelly structure, but appear to be fragments of brown hematite formed elsewhere and washed into the cavities, after having been rolled in water. In fact, these Carinthian nodular ore pockets, which are in a great bed of Triassic dolomite, contain red earth in which there are masses and ore nodules formed of quartz grains, zircons, rutiles, garnets, tourmalines, splinters of epidote and hornblende, the material being the residue of crystalline rocks destroyed elsewhere on the earth's surface.

[1] A. W. Stelzner: 'Ueber die Bohnerze der Villacher Alpe.' *Verh.* d. k. k. geol. Reichsanst., 1887, p. 219.

The deposits mentioned below are the most important examples of this class, but at present no ore deposits of this kind, *i. e.* as fillings of open pits, are anywhere of great importance.

Many funnel-shaped deposits of this kind were formerly worked in the Suabian Alps, supplying the local iron furnaces. A section of one of these Suabian pockets of nodular ore[1] which held, however, only a small amount of iron ore, is quite interesting on account of the great variety of the inclusions, and is reproduced in Fig. 247. The nodular ore of this region is found in cavities in the Franconian dolomite (upper white Jura), which forms the surface of extensive plateaus. Mention may also here be made of the re-

Fig. 248.—Cross-section of the old nodular ore mine near Roeschentz. (Gressly.)
l, limestone (white Jura); t, clay; b, limestone breccia; e, nodular ore.

markable discovery of the teeth of an anthropoid ape in a deposit of nodular ore in the Suabian Alps, described by W. Branco.[2]

A second well-known German occurrence of nodular ore is in the Jura district, of the southern part of Baden. According to the older descriptions, however, the ore occurred not as the fillings of cavities, but as a surface formation of considerable horizontal extent, lying either on the white Jura, or more rarely on the Muschelkalk, being in part concealed by alluvial débris. The 70 or 80 mines once in operation have been idle since the beginning of the 1860 decade. At this place the ore-bearing layers alternated with those of sand, limestone conglomerate and drift. Besides the ore, there

[1] Graf F. v. Mandelsloh: 'Geogn. Profile der schwäbischen Alp,' 1834.

[2] Branco: 'Die menschenähnlichen Zähne aus dem Bohnerz der schwäbischen Alp.' Stuttgart, 1898.

was also found jasper in the form of nodules, whose concentric layers enclosed druses of calcspar, gypsum or quartz. A distinction was made between pure ore (Reinerz) and pisolite ore proper (Bohnerz). The former is an earthy lamellar or compact or fibrous iron ore, occurring either in patches, or in the form of kidneys and nodular concretions up to 2 ft. thick. The center of the kidney-shaped formations is either earthy or is hollow and lined with hematite incrustations, fibrous limonite, crystals of brown spar, siderite or calcite. The 'bean' ore consists of concentric concretions of brown hematite varying from the size of a pea to that of a walnut, and forming a continuous series of nests and beds. The associated mammalian remains and sharks' teeth found in the deposits show that the ores were deposited in Tertiary time. Whether the limonite concretions and jasper nodules were secreted in place or come from disintegrated Jurassic rocks does not seem to have been determined with certainty.

Similar deposits are very widely distributed in the Swiss and French Jura, for example in the region of Laufen and Roeschentz in Switzerland. The multiform ore concretions lie in variegated, red or yellow clays, within irregularly branching cavities. Masses of nodular ore occur both above and in part concealed in the cavities. At Roeschentz such cavities when opened by small shafts were found to be connected in depth with irregular horizontal cavities also containing workable ore. A description by Gressly[1], whose conclusions are altogether opposed to the views presented here, gives important details of the exposures disclosed by mining operations. The cross-section, Fig. 248, is from this work.

[1] A. Gressly: 'Sur le Jura Soleurois.' *Neue Denkschriften.* Neuchâtel, 1841, Vol. V, pp. 245–349.

DETRITAL DEPOSITS.

By detrital deposits we understand accumulations of ore formed by the destruction and redeposition of primary deposits. These two results have been accomplished, in the main, in a mechanical, but in part, also, in a chemical way. In both cases water was the main agent used by nature for the purpose. Such a destruction and redeposition of primary deposits may have taken place in remote geologic periods, but only in comparatively rare cases have the products of such periods been transmitted to us in a recognizable condition. On the other hand, the Tertiary and Pleistocene formations of the earth's surface contain a great number of such detrital deposits, as they are commonly called. It is customary to use the term placer gravels for the Pleistocene and Tertiary alluvial gravel deposits, but this term is not extended to older deposits of this kind, though they may be completely equivalent to them genetically; at most they are called 'fossil placers.'

A. OLDER DETRITAL DEPOSITS.

I. DETRITAL DEPOSITS OF IRON ORE.

I. Detrital Deposits of Limonite in the Cretaceous Formations.

(a) In Lower Cretaceous Rocks.

The Iron Ore of Salzgitter and of Dörnten, North of Goslar.

These deposits, which are of considerable economic importance, occur in a range of hills formed by a steep, narrow, northwest-southeast anticline of Neocomian, Jurassic and Triassic strata, the ore bed outcropping along the flanks of the anticline in two approximately parallel zones.

The Salzgitter deposit is a distinctly stratified bed 3 to 25 m. thick, consisting of rounded or angular fragments of limonite, with some phosphate nodules, bound together by a ferruginous and in part somewhat silicious cement poor in lime. The fragments come from the Middle and Lower Dogger, the Lias, Keuper, Muschelkalk and Bunter sandstone. Worn Liassic ammonites are quite common in these masses. That the deposition of the hematite pebbles took place in Neocomian time is proved by the presence of the characteristic cephalopods of that age, enclosed in the ore

bed, especially species of *Perisphinctes* and *Olcostephanus,* and further southward also *Ecl~~a~~mnites subquadratus* Röm. These ores are underlain to the north by a great variety of Triassic and Jurassic strata. The ore beds are overlain by various strata ranging from the middle Gault to the Minimus clays of the upper Gault. From these facts it is inferred that the deposit was formed by the destruction, elaboration and partial re-deposition of the Jurassic and Triassic beds. It is a shore deposit formed by the transgressing sea of the Older Cretaceous, in which the ironstones, originally scantily distributed throughout the most diverse older horizons, were concentrated as a result of their hardness and weight.

The chemical composition of the Salzgitter ores is shown by the following analyses:

	I.	II.	III.
SiO_2	19.32%	19.73%	19.66%
Fe_2O_3	52.09 "	52.79 "	52.66 "
Mn_2O_3	1.07 "	0.57 "	1.15 "
Al_2O_3	4.36 "	3.55 "	4.68 "
CaO	5.27 "	4.47 "	7.54 "
P_2O_5	1.67 "	0.99 "	1.73 "
H_2O and CO_2 (combined)	12.21 "	11.63 "	13.01 "
H_2O (hygroscopic)	4.00 "	5.28 "	
Fe	36.46 "	36.96 "	36.86 "
Mn	0.75 "	0.40 "	0.80 "
P	0.73 "	0.42 "	0.76 "

According to R. Boettger, some samples of the ironstone of Salzgitter contain vanadium. Mining on a large scale began about the middle of the 19th century. The northern mines, and the Fortuna among the southern, are now abandoned. The Georg Friedrich mine, near Dörnten, belonging to the Ilsede furnace, on the contrary, is still active.

(B) In Upper Cretaceous Rocks.

1. *The Iron Ores of Ilsede.*[1]

Iron ore deposits that have been worked since 1860 occur in Hanover, near Ilsede. These deposits form a bed intercalated in the Senonian chalk.

1. Between Adenstedt and Gross-Bülten 2.5 k. (1½ miles) west of Ilsede, there is a bed 8 to 9 m. (26.2-29.5 ft.) thick opened to a length of 4 km. (2.4 miles) on the strike. 2. Between Lengede and Bodenstedt, 10 km. (6 miles) southwest of the Ilsede furnace, a bed 2.2-7 m. (7-22 ft.) thick is worked, and has been followed to a distance of 2.1 km. (1.26 miles)

[1] A. v. Strombeck: 'Ueber die Eisensteinablagerung bei Peine.' *Zeit.* d. D. G. G., 1857, Vol. IX, pp. 313–322. D. A. Brauns: 'Ueber die obere Kreide von Ilsede bei Peine,' etc. *Verh.* d. naturh. Vereins zu Bonn., Vol. XXXI. Also, 'Ueber das Eisensteinlager von Ilsede,' *Z.* f. d. ges. Naturw. zu Halle, XLIII, p. 280. Mr. Hoyer has furnished the notes for the summary here given.

along the strike. At both mines the ore bed, with its underlying and overlying strata, is actually the greatly depressed, much fissured flank of an anticline, whose opposite flank has, for the most part, been removed by denudation. Remnants of the bed in the drift of Hohenhameln and Hoheneggelsen, as well as of Ilsede, and other facts indicate a former much greater extension southward.

Reference to the Senonian is substantiated by the fossils present in abundance in the cement of the detrital deposit, such as *Ostrea diluviana* Sow., *Janira quadricostata* Sow., *Terebratulina striata* d'Orb., *Belemnitella quadrata* d'Orb., as well as by ammonites up to 95 centimeters in size, of the subgenus *Placenticeras*. In the overlying strata, moreover, where they have not been removed by denudation, the typical Senonian everywhere follows, but the stratigraphic relations indicate that the ore was deposited transgressively on various older limestone strata.

The ore consists of fragments of brown hematite of globular to ellipsoid shape, varying in size from that of a nut to that of a fist. The pieces are mostly angular and sharp-edged, but some of them have been rolled; they are cemented by a yellowish-brown marl or earthy limonite. Some of the cobbles are hollow geodes whose walls show a well marked crust structure and whose interior frequently contains druses of pyrolusite, psilomelane, calcspar and rhodochrosite.

The brown hematite fragments as well as the phosphate nodules which not infrequently accompany them are derived from the erosion of beds belonging to the Gault, for they often enclose remains of *Acanthoceras Millettianum* d'Orb., and *A. Cornelianum* d'Orb., fossils characteristic of the Gault of this region. These fragments represent the most resistant parts of the destroyed Gault strata assorted by the transgressing sea. On the other hand, no Jurassic remnants were found in them. From what has been said, it appears that the term pisolitic ores (Bohnerze), sometimes used for these ores, is entirely inappropriate.

Manifestly the chemical composition of a formation of this kind must vary greatly, so that only an average analysis is of technical value. For the Ilsede iron ores it is as follows:

Fe	34.8%
Mn	3.9 "
SiO_2	6.6 "
Al_2O_3	3.4 "
$CaCO_3$	10.0 "
P	1.1 "
S, MgO	Traces.

The production of the iron mines of the Peine district for 1898 was 516,225 tons.

Entirely analogous but smaller deposits are known at the Gehrdener Berg, near Hanover.

2. *Tertiary Alluvial Deposits of Magnetite and Red Hematite of the Banat, Hungary.*

A deposit of this class occurs on the broad mountain ridge of Pojana Wertop, 4 km. (2.4 miles) south of Bagschan in southern Hungary. It consists of Tertiary stream gravels, which rest on crystalline limestone belonging to the crystalline schists. The gravel consists of the typical rocks of the Dognacska-Moravicza mineral zone (page 590), viz., crystalline limestone, garnet rock, magnetite and hematite, besides various crystalline schists, banatites and other rocks. Both magnetite and hematite occur in rounded pebbles and blocks sometimes weighing as much as 7 to 8 tons, the ore being mainly concentrated in the deepest layers of the gravels. The gravel beds are in places 164 feet (50 m.) thick. The ores are extracted by open cuts, all material above 0.16 feet in diameter being saved. The ore constitutes from 20 to 33⅓ % of the mass. In 1894 the locality yielded 4,100 tons of ore.

II. Ancient Deposits of Gold-Bearing Gravels.

1. *The Gold-Bearing Cambrian Conglomerates of the Black Hills in Dakota.*

The 'cement' deposits of the basal conglomerates of the Cambrian beds of the Black Hills are, according to Devereux[1] and Irving, fossil gravels. At the base of a series of Cambrian rocks that rest directly upon upturned schists there is generally a bed of gravel, which in the vicinity of the Homestake lode is gold-bearing and has yielded heavily[2]. The conglomerate is usually 3 to 4 ft. thick and grades upward into a hard, dense quartzite. The auriferous portion occupies irregular depressions in the old schist surface, and was probably not uniformly distributed over the old shore line. The gravel is composed of rounded waterworn fragments of schist, the gold-bearing portions being cemented by oxide of iron or pyrite. The gold is rounded, worn by attrition and concentrated on the bed-rock. According to Irving it was derived from gold-bearing Algonkian schists. There is also in places an enrichment due to ferric sulphate solutions and possibly to the intro-

[1] W. B. Devereux: 'The Occurrence of Gold in the Black Hills,' *Trans.* Am. Inst. Min. Eng., 1882, Vol. X, p. 465. F. C. Smith: 'The Potsdam Gold Ores of Black Hill,' *idem*, 1898, Vol. XXVII.

[2] Excerpt from 'Ore Deposits of Northern Black Hills,' J. D. Irving, *Bull.* 225, U. S. Geol. Surv., p. 131. See also 'Geology of Homestake Lode,' S. F. Emmons, professional paper No. 26, U. S. Geol. Surv., 1904.

duction of pyrite that followed rhyolite intrusions. The greater part of the auriferous gravel was derived from the Homestake lode.

Gold also occurs as thin continuous films between the fracture planes of schist fragments and as fine specks between the layers of the schist directly underlying the conglomerates. This gold has been deposited from chemical solution as noted above.

In Deadwood and Blacktail gulches, which cut into the gold-bearing formation, as well as into the country rock, recent alluvial gold gravels were formerly worked which contained the metal in the form of a twice redeposited product.

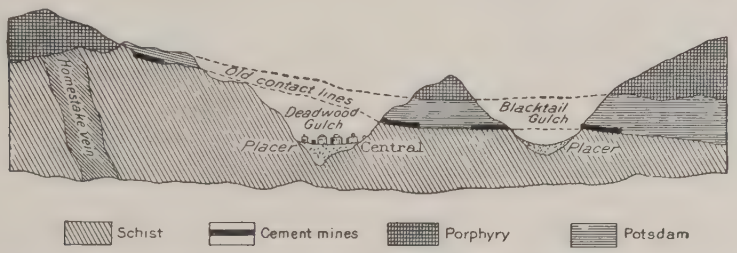


Fig. 249.—Approximate geological sketch from Homestake eastward. (Devereux.)

According to J. D. Irving,[1] gold is also found in the higher Cambrian strata—as at Spearfish Creek—although not in workable amount.

As shown in Fig. 237, the Cambrian formation of the Black Hills contains intercalated gold deposits which were formed by subsequent mineralization of calcareous rocks.

2. *Gold-bearing Detrital Deposits of Carboniferous Formations.*

In Australia auriferous detrital deposits occurring in the Carboniferous have been known for a long time. Thus, R. Daintree[2] described the occurrence of gold in water-worn particles in a conglomerate of the Carboniferous (glossopteris stage) near Peak Downs in Queensland. It is also known[3] that the lowest strata of the Carboniferous rocks which cover broad areas in the region north of Gulgong, in New South Wales, sometimes carry gold in paying amount. The gold-bearing conglomerates discovered by Clarke at Tallawang, in Phillips county of the same colony, are of identical age. In Tasmania gold was found in the coal measures of Hobart.

[1] J. D. Irving: 'A Contribution to the Geology of the Northern Black Hills,' *Annals* New York Ac. of Sc., Vol. XII, No. 9, p. 296. Also, 'Geology of the Northern Black Hills, South Dakota,' *Bull.* 225, U. S. Geol. Surv., p. 131. Also, 'Economic Geology of the Northern Black Hills,' Prof. paper No. 34, U. S. Geol. Survey, 1904.

[2] R. Daintree: 'Occurrence of Gold in Australia,' *Quart. Journ.* Geol. Soc., 1878, Vol. XXXIV, p. 435.

[3] Phillips-Louis: 'Ore Deposits,' 1896, p. 649.

In America we may mention the case of Corbett's Mills in Colchester county, Nova Scotia, described by Dawson and F. Harth,[1] where rounded gold grains are found in a Carboniferous conglomerate, which, it is to be noted, is traversed by gold quartz stringers. European deposits of this kind have been known for some time. Gold has been extracted from the lower Carboniferous conglomerates of Bessèges in southern France (department of Gard), according to Phillips[2].

3. *Gold Deposits of the Mesozoic Formations.*

The gold-bearing conglomerates of the Mariposa formation (Marine Jurassic), in Placer county of the Sierra Nevada region of California, are of special interest. According to Lindgren,[3] they contain finely divided gold, with some pyrite, but no magnetite nor ilmenite. As the Mariposa strata are traversed by some of the largest gold quartz veins of the Sierra Nevada, these conglomerates, if their gold was not really formed by later impregnation, indicate an older and now destroyed group of primary gold deposits in California.

Other gold-bearing Mesozoic conglomerates are known in the northern part of California on Klamath river and in Siskiyou county. These were regarded by Dunn as old river gravels, but according to Diller[4] they contain marine fossils. The gold is accompanied by red hematite and pyrite.

Mesozoic gold-bearing sediments are also found in Australia and in New Zealand. In the Otago, Nelson and Southland districts of that colony such sediments are found in the Jura, and at Mt. Buster in the Cretaceous.[5]

Tertiary gold deposits having the character of true placer gravels will be mentioned under the latter title.

III. Lead- and Copper-bearing Permo-Triassic Gravel Deposits.

The Copper and Lead Deposits of Cap Garonne, near Toulon.

According to B. Lotti,[6] quartz conglomerates of the Permo-Triassic series enclose an ore-bearing zone 0.5 to 1.2 m. thick at Cap Garonne. The pebbles composing the conglomerates consist of vein quartz in a cement

[1] G. Becker: Cited in *Zeit. f. Prak. Geol.*, 1898, p. 217.

[2] G. Becker: *Zeit. f. Prak. Geol.*, 1898, p. 216.

[3] W. Lindgren: 'An Auriferous Conglomerate of Jurassic Age from the Sierra Nevada,' *Am. Journ. Sci.*, 3d series, 1894, Vol. XLVIII, p. 275.

[4] Cited in *Zeit. f. Prak. Geol.*, 1898, p. 216

[5] H. A. Gordon: 'Hysteromorphous Auriferous Deposits of the Tertiary and Cretaceous Period in New Zealand,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, p. 292.

[6] B. Lotti: 'Sul giacimento sedimentario cuproplumbifero di Cap Garonne,' Rassegna Min., Vol. XIV, No. 16, 1901. Also *Zeit. f. Prak. Geol.*, 1901, pp. 281–283.

of kaolin or mica. In the upper portion of the bed granules and crystals of galena with barite are interspersed, while in the lower part black oxide of copper (melaconite) occurs mixed with copper glance and remnants of still undecomposed copper pyrite. From the occurrence of copper glance in the interior of large quartz pebbles and of fragments of copper pyrite in the cement, B. Lotti infers that we have here a genuine detrital deposit. The ores are believed to be derived from Cambrian and Archean rocks underlying the Permian. These older rocks do actually contain many quartz lenses and veins with galena, zinc-blende, copper pyrite and bournonite which are worked at Bormettes, Verger, Rieille, Cogolin and elsewhere.

B. RECENT PLACER GRAVEL DEPOSITS.

General Characters.

Placer gravels are deposits of loose, more or less rolled, material derived from the destruction of older deposits, lying on the earth's surface, or at least very close to it, and containing paying amounts of ore or precious stones. Gem gravels are not treated in this work. As the ore in the gravel is usually seen even by an inexperienced observer, and since the metallic particles can generally be easily extracted by simple washing, the gravels have almost always been the first objects of mining in the history of a country. For this very reason they were usually the first of all the deposits of a country to be exhausted. Thus, for example, practically nothing remains of the old gravel-mining industry of Germany and Austria, though it was formerly quite important. In newly discovered or recently explored countries, however, placer mining often develops into vast proportions as the first phase of mining. Hence in selecting examples of gravel deposits for description we are, practically, limited to such regions.

According to the nature of the paying metal or ore in the gravels, we may speak of gold gravels, platinum gravels, tin gravels, etc., but the expression iron-ore gravels is but little used.

As the material composing placer gravels has been exposed to all the influences of the atmospheric air and of the water seeping through the upper strata of the soil, placers will be found to contain, in the main, only relatively insoluble, and in general refractory metallic compounds which, moreover, are protected by their great specific gravity against easy removal by water. The insoluble native metals, such as gold, platinum and others, and oxidic ores (tin-stone, magnetite and others) are naturally most common. Easily oxidizable metals and metallic sulphides will not, as a rule, be found in gravels. In the destruction of older deposits, minute and scantily interspersed me-

tallic compounds may be preserved, provided they possess the necessary insolubility and weight, and thus we find that metals which are otherwise most scantily distributed, such as platinum, which in its original site would hardly anywhere pay extraction, are concentrated within the gravels in paying amounts[1].

These placer gravels are usually grouped into two classes, according to their position with reference to the deposit from which they are derived, and in part, also, according to the manner of the original process in which they are derived from the primary ore deposit:

1. *Residual gravels, i. e.,* of local origin (eluvial gravels).

2. *Alluvial gravels, i. e.,* formed by washing. These may again be subdivided according to age into Recent, Pleistocene and Tertiary gravels.

Residual gravels, the rarer of the two groups and certainly the less extensive, are found in the immediate vicinity of the original ore deposits, and quite independent of water courses, viz., on mountain slopes, plateaus and sometimes even on mountain summits. As they consist of the residual products left in the weathering of the original ore-bearing material, they contain almost no foreign matter, and they are distinguished by a great uniformity of material as compared to the gravels transported and assorted by water. The rounding of their constituents is but very slight; the larger fragments are found to be but slightly abraded along the edges, and there has hardly been any sorting of the material according to size. This detrital gravel is the work of air and rain, the same agents whose activity is so marked in the formation of gossans; in fact, gossan and residual detrital gravels often pass one into the other. Changes of temperature also have a share in the disintegration of original deposits, and the wind contributes to the sorting of the fragments, according to size. In arid regions and under a tropical sky, the extreme difference of temperature between the day with its burning solar heat, and the quickly ensuing night with its tremendous radiation, cause an extensive crackling and disintegration of the outcrop of the primary deposit. Even hard masses are splintered. The wind starts up the débris thus formed, sweeps away the finer particles, and leaves the larger fragments and the heavier of the smaller pieces behind. Showers of rain wash the heavy ingredients a few meters downward, in case the ground has a little slope, or spread them out in all directions on level ground. Thus, in the case of local or residual gravels, there has often been both a chemical and a mechanical redeposition of the original metalliferous material in place, but no transportation of it to any great distance.

On the contrary, the gravels formed by the transporting and washing ac-

[1] B. v. Cotta: 'Erzlagerstätten I,' Freiberg, 1859, p. 100. C Zerrenner: 'Anleitung zum Gold,- Platin- und Diamantenwaschen aus Seifengebirge,' etc., 1851.

tion of water are found only in the channels of brooks and rivers, in fresh water lakes or along the sea-coast. They lie for the most part within the present valleys or along the present shore, but are also often found in stretches of fluviatile sediments, sometimes intersecting the present direction of the valley on old river terraces, or in sheets covering plateaus (California, Ohlapian in Transylvania) and finally in old shore terraces above the present level of the sea. Their material is always much rolled, and for the most part is assorted, according to the size of the ingredients, into shingle, gravel, sand, clay, mud, etc. The same is true also in part of the ore content therein.

In the placer gravels the ore is ordinarily distributed in a peculiar way, as may be seen from the diagrammatic longitudinal section of a placer deposit of this kind found in the Ural (Fig. 250). The particles of

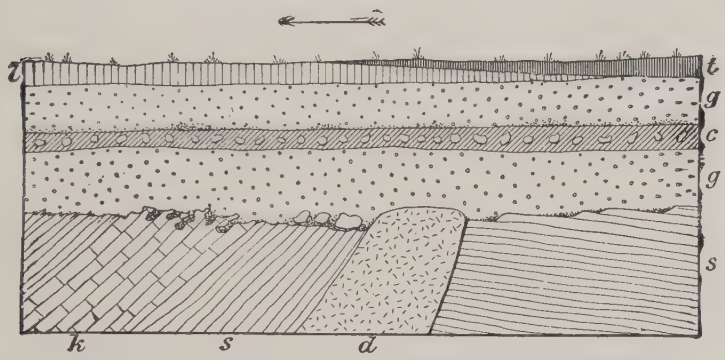


Fig. 250.—Ideal section of a gold placer deposit.

s, slate; k, limestone; d, diabase; g, gravel; s, sand; c, conglomerate; l, loam; t, turf.

the heavy metal are concentrated to a remarkable degree upon the bedrock or along the surface on which the alluvial masses were laid down. The higher strata are ordinarily very poor, and are not sluiced, being thrown on the dump. The larger nuggets, found as rarities, almost always occur at the base of the gravel beds. The character of the bedrock and the condition of its surface materially influence the richness of the gravel layer directly above it. Rocks such as limestone and dolomite, which are corroded and abraded by running water in such manner as to assume a roughly pitted or gouged surface, catch the heavy metallic particles in the depressions, while those rocks which are polished smooth by water, such as many fine-grained gneisses, eruptive rocks, diabase and others, are unable by their outcrop to stop the heavy grains of metal rolling over them. Those rock strata are the best collectors which are steeply inclined and dip in the di-

rection of the former river course; horizontal or backward dipping beds are much less effective. Many schistose rocks, which show exfoliation in their outcrops in the river bed, catch the finest particles of heavy metals between the loosened folia, so that the uppermost part of the outcropping schists may sometimes be worked for gold or platinum, as in the Ural. If large boulders occur in the lower layers of the gravels, rich pockets are often found between them.

Sometimes the bedrock on which the gravels rest shows narrow grooves or troughs of considerable length which are apt to be particularly rich (see Fig. 255), or the surface may contain pot-holes (pockets) with an exceedingly rich yield. Down stream below such rich pockets, if the overlying soil is small in amount and there has been a partial natural removal, this wealth is wont to be expanded fanlike in steadily diminishing amount. Hence the practical prospector, rendered alert by such expansions, is often able to recognize the direction in which a rich pocket is situated.

Where a gravel deposit contains an impervious layer intercalated in it, such as a sand or gravel with firm ferruginous cement (**false bedrock**), the heavy metals are often concentrated on the surface of this layer, so that the deposit may have two or more workable layers. This is also true in cases in which lava streams flowing into and spreading in valleys have temporarily interrupted the deposition of gravel, sand or clay, a phenomenon repeatedly encountered in western North America and in Australia.

As such intercalated layers of solid material were often regarded as the real bedrock, the error being perceived only later, they were called "false bedrock" (*loshnyi plotik* in the Ural).

In some cases gold-bearing layers occur at several higher levels. Thus K. Schmeisser[1] says that the section seen in the shaft of the Ross United Gold Mine, at Hokitika on the south island of New Zealand, shows no fewer than eight layers, carrying a considerable gold content, though not in any case workable.

It would, however, be an error to assume that in a cross section of a river valley the lowest layers of shingle, gravel or sand are throughout the richest. On the contrary, the values in this horizon are variable and pay gravel is ordinarily limited to streaks of greater or less width, which are found in one place in the center of the valley, in another along one side, now nearer, now further away, from the present water course. Several such rich streaks may even run side by side through the alluvial valley lands, but only in its lower course, where the fall of the stream is slight.

The presence of the gold in the lowest layers of stream gravels was for-

[1] K. Schmeisser: *Australasien*, p. 90.

merly regarded as due entirely to a natural process of concentration by gravity during deposition. This process is indeed possible in some cases, but in many other cases, as correctly pointed out by F. Posepny[1], this assumption alone will not suffice. The material of the gravel is in many cases not "classified and sorted," but forms an alternation of layers showing great diversity in size of grains and pebbles. Where the coarsest and heaviest material lies lowest, as is so frequently the case, while higher up the material becomes lighter and lighter, we must remember that these layers were deposited one after the other, perhaps at long intervals. It is only in narrow gorges that all the material covering the bottom land was carried down into the valley and deposited by a single flood.

The accumulation of the finer metallic particles at the bottom of loose alluvial masses is much more satisfactorily explained by the assumption of a subsequent downward migration of these particles, as was also pointed out by F. Posepny. Every assayer is familiar with the fact that slight shocks to a cup containing a powdered sample of ore suffice to make the heavier metallic granules slip down through the lighter barren particles and become concentrated at the bottom. Even in undisturbed masses of considerable size, like the piles of crushed ore at the Pribram works, this action may be observed, according to F. Posepny. If the heaps are examined after being untouched for some time, the galena particles are found to be concentrated at the bottom. In porous deposits of gravel and sand, which are traversed by vigorous ground-water currents, as is usually the case in gravels, and in which, therefore, the smallest particles are subject to the thrust of the water, such a gradual sinking of the finest particles of heavy ores may readily be possible. In fact, archæologists have long been familiar with the phenomena of the sinking of coins and the like in loose soil, and Helmhacker very properly explains the rare occurrence of metallic lead in the lower layer of placer gravels of the Ural to be due to the gradual downward movement of particles of shot from the guns of hunters who have discharged their weapons in this vicinity.

The interesting question whether the concentration of certain ores occurring in gravels (native gold, tinstone) is also possible in a chemical way by means of chemical solution and subsequent precipitation will be discussed for the various classes of gravels in subsequent pages.

From what has been said, it is evident that certain alluvial gravels may, after certain intervals, acquire new wealth. Such examples are well known in the flood plains of many large rivers of Australia; for example, Buller River, and in the Otago district of New Zealand. According to K. Schmeis-

[1] F. Posepny: 'Genesis,' p. 207.

ser,[1] the Clutha River in the Otago gold field supplies new and rich material to the gravels at every melting of the snow.

In some regions the gold-bearing gravel brought down by the river finally reaches the ocean, as seen on the east coast of Australia between the Clarence and Richmond rivers, and along the coast of Oregon in the United States, and at Vladivostok in southeastern Siberia. The sea itself by the alternation of tides and the play of breakers liberates the heavy metallic particles from the rocks of the coast. On the coast near Naples, for example, the sea has formed deposits of magnetite-augite sand out of the detritus of the lavas of Vesuvius. On the coast of the Baltic (for example, at Warnemünde), the ore particles of the Pleistocene strata outcropping on the shore are locally enriched; the northern drift marl especially, with its multitude of fragments of crystalline rocks, contains such ore grains. According to Deecke, the water in its concentration of such sands, which may eventually contain in local areas as much as 64% of iron ore, is aided by the wind, which at ebb tide blows away the light grains of quartz and silicates.

If a stream whose gravels contain metallic grains be followed down from its source to the sea, the size of the heavy metallic particles in the gravels may often be seen to diminish more and more. Large rivers, as a rule, are able to carry out to the sea only the finest particles; only short, vigorous mountain torrents along steep or precipitous coasts are able to carry the heavier grains into the sea.

Conversely, in many cases, on proceeding up stream through a placer-bearing river valley, a place will finally be reached where large fragments of ore will be found with part of the gangue still adhering, and where the fragments of ore are but little rounded by rolling and may even still exhibit crystalline forms. Finally the prospector may discover on the slope of the main valley or on the side of the valley the deposit which supplied the river, which may be a workable vein or stock. Often, however, the ore in the alluvial sands of the upper river course suddenly stops without any genuine deposit being found, despite the most active search. This simply means that the upper limit has been reached of those rocks which contain sparsely distributed ore, perhaps only in minute particles, which have been concentrated in the river gravels. Thus, in the Ural, the platinum of the alluvium comes to an end as soon as the upper limit of the olivine rock or of serpentine has been reached in the river valley. Concerning the nature of the primary deposit which is to be looked for, the attentive observer will sometimes find useful indications from the presence of characteristic associated minerals in the placer gravels. Thus, in the Ural, long before actual

[1] K. Schmeisser: Australasien,' p. 100.

proof had been obtained that the platinum came from olivine rocks, this origin was surmised from the fact that chromite was found accompanying it, and eventually particles were found which showed platinum intergrown with chromite. In some cases even the less valuable or worthless companion minerals may draw attention to the ore in the gravels themselves, as, for example, the blackish magnetite and ilmenite sand which so often indicates gold. In searching for gold-bearing marine gravels especially, such blackish sand may put the prospector on the right track.

Youthful as the placer gravels are, geologically considered, yet in many cases they have already suffered dislocation. Numerous ex-

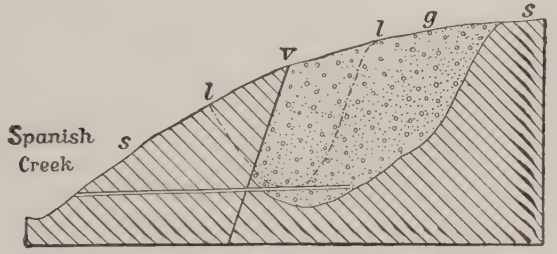


Fig. 251.—Cross-section of a faulted gold placer gravel deposit, Spanish Creek, Cal. s, slate; g, auriferous gravel; v, fault; l, boundary of old channel.

amples are known from California of faults traversing both gravel beds and the country rock, and often materially affecting the mining operations. Figure 251 represents such a case, which shows plainly that the fissure was only formed after the deposition of the gravel. Sometimes basalt dikes have arisen along such displacement fissures, as in several cases in Plumas and Sierra counties of California. Slightly folded gravel beds have also been observed in that country.

The following detailed descriptions of typical examples illustrate the several varieties of gravel deposits grouped according to the kind of ore obtained from them:

Placer Gravel Deposits of Various Kinds.

(a) Magnetic Iron Ore Gravels.

Near the mouth of the St. Lawrence river the north bank shows vast deposits of titaniferous magnetite sands derived from the norites outcropping in the upper basin of the stream. The best known deposits are those of Moisie bay, near the mouth of Moisie river. Others are found in the vicinity of Mingan, Bersimis, Natasquan, Kagashka and Batiscan.

The magnetite sands occur in layers several centimeters thick in the ordinary river sand. An especially rich sample from Moisie contained 70.10% of ore carrying 55.33% Fe and 16% Ti O_2.[1]

Similar sands are also found on the shore of Lake Champlain.

Gold-bearing magnetite sands are also known on the west coast of North America between Cape Mendocino in California and the mouth of the Umpqua river in Oregon.[2]

Titaniferous magnetite sands are found for a distance of 13 miles along the southwestern coast of the north island of New Zealand,[3] near the town of New Plymouth, and were proved by dredging to extend outward for a distance of three miles from the land. The source of this deposit must be the volcanic area around Mt. Egmont. Smelting experiments were made with these sands, which were briquetted with clay. The sands contained 52.88% Fe_2O_3, 29.60% Fe O and 8.14% Ti O_2.

Similar sands found on the west coast of the south island are gold-bearing and were washed for that metal.

Titaniferous magnetite sands are also known from the shore near Yamakushinai, province of Iburi, and near Kobui, province of Oshima, on the Japanese island of Yesso.[4]

In Europe titaniferous magnetite sands were found on various coasts with volcanic rocks, as, for example, at some points in the Bay of Naples, but nowhere in payable deposits.

An occurrence known to Agricola, but of no importance as a source of ore, though geologically interesting, is found in the Seifengründel (Seufzergründel) near Hinterhermsdorf in Saxon Switzerland.[5]

At that place a tiny brooklet flows into the Kirnitzsch river from the west, and, despite its present small volume, has formed extensive deposits of stony clays and sands along its little valley. At the Hohwiese these alluviums, probably of late Pleistocene age, are underlain by thin layers of black sand, and this material is also found between the boulders of the lower course of the brook. The sands are not only exceedingly rich in magnetite, but they also contain quartz, hornblende, augite, bronzite, yel-

[1] J. F. Kemp: 'A Brief Review of the Titaniferous Magnetites,' School of Mines *Quarterly*, 1899, Vol. XXI, pp. 331–333.

[2] Phillips-Louis: 'Ore Deposits,' 1896, p. 26.

[3] E. Metcalf Smith: 'On the Treatment of New Zealand Magnetic Iron Sands,' *Journ.* of the British Iron and Steel Inst., 1896, I, p. 65.

[4] J. F. Kemp: 'A Brief Review of the Titaniferous Magnetites,' School of Mines *Quarterly*, 1899, Vol. XXI, p. 65.

[5] A. W. Stelzner: 'Ueber das Vorkommen von Edelsteinen in der sächs. Schweiz,' *Sitzungsber.* d. Isis., Dresden, 1870. O. Herrmann and R. Beck: 'Erläut. zur geol. Spezialk. von Sachsen.' Sect. Hinterhermsdorf-Daubitz. H. Oehmichen: 'Die böhmischen Granatlagerstätten und die Edelsteinseife des Seufzergründels bei Hinterhermsdorf,' *Zeit. f. Prak. Geol.*, 1900, pp. 13–17.

lowish hyacinth, dark spinel (ceylonite) and more rarely green diopside, apatite, and finally, in more isolated instances, ruby. The source of the iron ore and its companion minerals (other than quartz) was a small stock of olivine and hornblende-bearing glassy basalt, situated a little above the Hohwiese. The basalt holds magnetite, bronzite, spinel and augite, and, in its brecciated contact zone with the Turonian sandstone cut by it, contains inclusions of a gabbro carrying medium grained bronzite and very rich in spinel.

(B) Lateritic Decomposition Products Rich in Iron Ore.

The laterites of Brazil, a geologically recent formation not older than the Pleistocene epoch, are rich in fragments of iron ore, described under the name of *tapanhoancanga*, after the sierra of the same name.[1] They are found in the province of Minas Geraes at the towns of Itabira, Villarica and Marianna, where they form a sheet 3 to 13 ft. thick, covering the outcrops of hematite schists and other crystalline rocks. The deposit consists of fragments and pebbles of micaceous hematite schist, hematite, magnetite and limonite, together with those of various crystalline rocks, especially quartzite and itacalumite. The cement, which is often scanty, is hematite. This deposit contains gold, diamonds, topaz, rutile, zircon and other rarer minerals.

A peculiar deposit of this class (laterite) is found in Surinam. According to G. C. DuBois,[2] the ferruginous laterite has a cellular slag-like surface and holds nodules and globular concretions, varying from the size of fine shot up to particles two centimeters across. These concretions have a scaly but not radial structure. They consist chiefly of limonite (86.9% F_2O_3), but also contain newly formed quartz, chalcedony and remains of silicates. Besides this concretionary limonite the laterite of Surinam also contains oolitic bauxite.

(C) Tinstone Gravels.

1. *The Tinstone Gravels of the Erzgebirge and the Neighboring Mountains.*

In view of the great number of primary tin deposits in the Erzgebirge of Germany it is not surprising that tin-bearing gravels are widely distrib-

[1] v. Eschwege: 'Beiträge zur Gebirgskunde Brasiliens,' 1832, p. 141. Pluto Brasiliensis, 1838, p. 225.

[2] G. C. DuBois: 'Beitr. z. K. der surinamischen Laterit- und Schutzrindenbildungen,' Tschermak's *Min. Mitth.*, 1903, Vol. XXII, p. 31.

uted in that region. These alluvial deposits were worked as early as the 12th century and as recently as the 19th century.[1]

Most of the tin-bearing gravels of the region occur in the granite areas or the adjacent contact zones. The deposits are of two kinds: (1) Residual formations, consisting of unassorted angular rock débris, that has moved but little down hill and may be found to extend far up the slopes, as in the region of the Greifenstein, near Geyer, and at numerous points near Eibenstock and Johanngeorgenstadt; (2) water-worn débris filling recent valley bottoms of Pleistocene and in one case Tertiary age. The recent and Pleistocene occurrences cannot be sharply discriminated in every case; the Tertiary occurrences will be specially described at the end of this chapter.

The valley gravels form more or less perfectly stratified beds of pebbles or sand, usually covered with sandy clays or peat, and composed mainly of rolled fragments of granite, and a variety of contact-metamorphic slates, especially andalusite-mica-rock and tourmaline schist, as well as vein quartz and vein breccias. The tinstone occurs mainly in minute granules, but also in larger grains, which sometimes still exhibit a crystalline form; in rare cases it was found in larger lumps, which, however, are always coalesced with quartz and represent fragments of greisen rich in cassiterite. Greisen débris, associated with fragments of tourmaline schist, is the best indication of the presence of tinstone in such gravels, a fact well known to the old placer miners of the Erzgebirge. Besides cassiterite, topaz, apatite, beryl, fluorspar and malachite were also found, and at various points free gold. Gold from the gravels of the region of Annaberg is mentioned in a decree by the Prince Elector of 1657, and was also known in the placers of Eibenstock and Johanngeorgenstadt.

The Tertiary gravels of the Erzgebirge are confined to the region of the Steinhöhe at Seifen, near Abertham,[2] where they occur under conditions quite analogous to those of the Tertiary gold gravels of California and the tinstone gravels of Australia, namely, in a remnant of an old river valley, protected from denudation by lava sheets. On the granite and the phyllite bedrock adjoining the granite, and altered by it through contact metamorphism as shown in Fig. 252, there rests a fluviatile deposit, about 10 m. (32.8 ft.) thick, which petrographically resembles the formations of the lower Oligocene. The basal and most widely distributed gravel bed

[1] H. Schurtz: 'Der Seifenbergbau im Erzgebirge und die Walensagen,' Stuttgart. 1890.

[2] G. Laube: 'Geologie des Böhmischen Erzgebirges I, Prague,' 1876, pp. 195, 197. A. Sauer: 'Erläut. zu Section Wiesenthal,' 1884, p. 81. F. Schalch: 'Erläut. zu Section Johanngeorgenstadt,' 1885, pp. 119–123. Lohrmann: 'Einiges aus der geolog. Vergangenheit des Erzgebirges,' Annaberger Berichte, 1898.

is from 10 to 20 ft. thick and consists of pebbles of granite, for the most part resembling greisen, of fine-grained granite, vein quartz breccia, tourmaline schist, andalusite-mica-rock, quartzite schist and phyllite quartz nodules. This material alternates with sands which are rich in black tourmaline granules and mica. Above this follows a red clay, 1 to 4 ft.; then a sandy yellowish or bluish clay, 1 to 2 ft., and finally quartz sand with cross bedding, 2 to 5 ft. thick.

The gravel series is covered by basalt, developed partly as nepheline and partly as leucite basalt, underlain towards the northwest by a thin phonolite sheet. The lower layers of this deposit contained so much cassiterite that it was extracted by underground (drift) mining and washed, the industry building up the town of Seifen. As the rocks south of the place are traversed by numerous tin veins recently worked at the Sanct

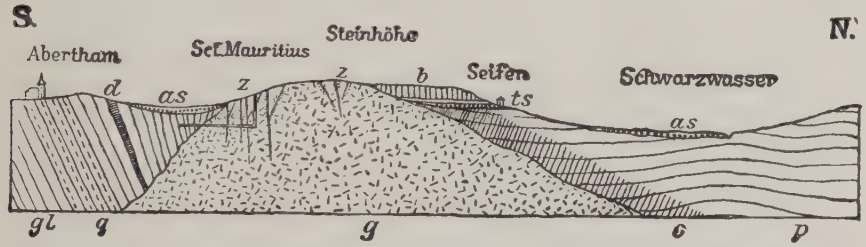


Fig. 252.—Ideal section through the tin district of Abertham in the Erzgebirge.

gl, mica schist; q, quartz schist; p, phyllite; c, contact-metamorphic schists; g, granite; z, tin veins with Zwitterzones; ts, Tertiary tin placers; b, basalt; d, diorite; as, alluvial and diluvial tin gravels in part with cover of bog.

Mauritius mine, the presence of tin in these Tertiary formations may be readily explained.

2. *The Tinstone Gravels of Cornwall.*

The tin-bearing gravels of Cornwall were formerly the most important alluvial deposits of Europe. The facts concerning this district have been summarized by Phillips and Louis,[1] from whose account the following notes are derived:

The following varieties of tin-bearing gravels (called "stream-works") are distinguished in Cornwall:

1. In gravels now forming in existing streams and on sea-beaches, in which the tin ore usually occurs in angular or sub-angular grains (valley gravels).

[1] Phillips-Louis: 'Ore Deposits,' 1896, pp. 28–33.

2. Tin gravels of valley terraces, old and elevated river deposits, occurring at various heights up to 700 ft. (210 m.) above the present water courses. Still older terraces at St. Agnes Beacon contain pebbles and grains of tin ore.
3. Tin-bearing angular débris at and below the outcrop of tin veins (residual tin-ore gravels).

One of the most interesting sections of Cornish tin gravels is that of the Happy Union stream works in St. Austell valley, near Pentewan harbor. In this valley just above St. Austell a number of small streams, which come from the granitic Hensbarrow mountains, unite and receive the tributaries from the tin region around Polgooth mine. The bedrock of the valley consists of slate rock.

According to J. W. Colenso, the section of the Happy Union stream works is as follows, from above downward:

9. River sand, silt, etc.	20 ft.
8. Sea sand with oak trunks and bones of *Megaceros hibernicus* (giant elk) and *Bos primigenius*	20 ft.
7. Silt with few stones and bone remains.	2 ft.
6. Sea sand with fragments of marine shells.	4 in.
5. Silt with Cardium edule.	10 ft.
4. Layers of leaves, acorns, moss, etc	6 to 12 in.
3. Layers of peat	6 to 12 in.
2. Tin ground where the whole of the ores occurs associated with débris of granite and tourmaline slate and in lumps up to 10 pounds in weight with some gold	3 to 10 ft.
1. Bedrock consisting of clay slate (killas) whose surface lies 18 m. (59 ft.) below the present high-water level.	

This part of the Cornish coast, therefore, has subsided since the deposition of the tin ore gravels. Farther up the valley the marine strata are lacking in the section of the tin gravels.

The tinstone of the Cornish gravels either forms more or less rounded grains and crystals, or it occurs in the form of wood tin, and in somewhat rare cases as pseudomorphs after organic remains. Particular importance attaches to the occurrence in the tin gravels of the Penetwan and Carnon valleys of fragments of stags' antlers that are partly impregnated with tinstone, iron oxide and some pyrite.

A specimen from the Penzance museum contained, according to J. H. Collins:

CaP_2O_5	80.04%
$CaCO_3$	2.24 "
CaF_2	0.50 "
FeS_2	1.66 "
Fe_2O_3	0.62 "
SnO_2	2.60 "
SiO_2	0.22 "
Organic substance and loss	12.12 "
	100.00 "

While there can be no doubt that by far the greater part of the tin ore has been brought together by the mechanical action of water, yet a small part represents segregations from solutions of tin oxide, which were formed probably within the gravels, or were conveyed to the valley bottoms with the ground-water current. Such re-deposited tinstone may be especially represented by the wood tin of the Cornish gravels.

The tin gravels of Cornwall were exploited as early as Roman and Greek times,[1] when Great Britain was called "Cassiterides" (tin islands). At present the true gravels of that country have long been exhausted and abandoned. What is called "stream working" at the present day is merely the extraction of the tinstone contained in the tailing of the stamp-mills of the valleys. In 1894 6% of the total tin production of Cornwall came from the washing of these lean slimes.

Tinstone gravels were formerly worked in Brittany and western Spain.

3. *The Tin-bearing Gravels of Australia.*

On the continent of Australia the most important tin gravels lie in New South Wales, near the Queensland boundary, in the New England district. They were discovered in 1853 by W. B. Clarke, but were not worked until 1872, though in the colony of Victoria tin gravels were washed some years earlier. The tin gravels of the New England district lie partly on the floor of the valleys of the present day and partly in portions of Tertiary valleys, which were left unattacked by denudation, being mostly protected by basaltic lava streams. The gravel tin is derived from granite masses which are permeated by numerous tin veins. Among the most important gravel areas of this region may be mentioned Bendemere, Watson's Creek, Stanthorpe, Copes Creek, near Inverell, and especially Vegetable Creek. Fig. 253 gives a picture of the conditions of bedding of the so-called "deep leads" of the locality last named. It shows the lateral flank of an old Tertiary valley bottom with its lava cover, which is here composed of several flows somewhat different petrographically. The gravels of this kind in Rose Valley near Vegetable Creek, discovered in 1880, yielded in 9 months 553.5 tons of tin. Besides these old gravels, the alluvial ones are exploited.

According to H. Louis,[2] the tin works of Vegetable Creek produced:

	1886.	1895.
Mines on veins	169 tons.	286 tons.
Alluvial gravels	761 "	499 "
Old Tertiary gravels	962 "	115 "
	1,892 tons.	900 tons.

[1] Blümner: 'Technologie, etc., bei Griechen und Römern IV,' p. 81 *et seq.*

[2] T. W. Edgeworth David: 'Geology of the Vegetable Creek Tin-Mining Field,' Geol. Survey of N. S. Wales, 1887, p. 23. Referred to by Phillips-Louis, 'Ore Deposits,' 1896, p. 662.

4. *The Residual Tin Deposit of Mount Bischoff.*

The greatest example of residual tin gravels known is found on Mount Bischoff in northwestern Tasmania.[1]

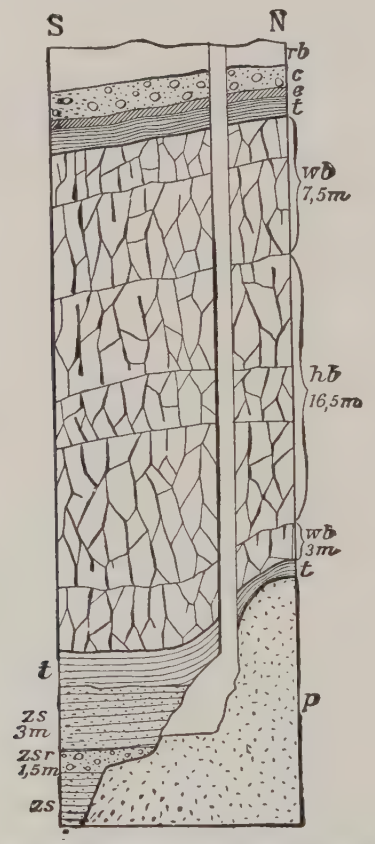


Fig. 253.—Vertical section of the old shaft of the Wesley Bros., Vegetable Creek. (Phillips-Louis.)

rb, red earth; c, conglomerate; e, ironstone; t, clay; wb, white basalt; hb, hard basalt; zs, stanniferous sand; zsr, pay streak; p, porphyry.

This mountain consists of Paleozoic clay slates and quartzites, with lesser amounts of sandstone and dolomite. The slate rock is traversed by numerous dikes of a quartz porphyry, which may be derived from the

[1] A. v. Groddeck: 'Zur Kenntniss der Zinnerzlagerstätten des Mt. Bischoff in Tasmanien.' *Zeit.* d. D. G. G., Vol. XXXVI, p. 642 *et seq.* W. Ferd. Kayser: 'On Mt. Bischoff,' Australas. Asso. for the Advanc. of Sc., Hobart, Tasmania, Sec. C., 1892. W. v. Fircks: 'Die Zinnerzlagerstätten des Mt. Bischoff in Tasmanien,' *Zeit.* d. D. G. G., 1899, Vol. LI, p. 431 *et seq.*

same eruptive hearth as a granite outcropping west of Mount Bischoff, at a distance of 3.5 km. (2 miles) in the form of a "massif." Altogether 17 large dikes of this kind are known at the mountain, showing great variety of trend, and forming the horseshoe-shaped crest of the summit. Towards the north and west tin veins and barren quartz veins appear, while at the foot of the mountain, at the northeast and south, a Tertiary basalt sheet with underlying clay conceals the bedrock proper.

The quartz porphyries, and in part also the slates traversed by them, have for a distance of ¾ km. (½ mile) from the mountain top undergone a very profound alteration, as shown first by A. von Groddeck and subsequently demonstrated in detail by Freiherr W. von Fircks. All the original feldspar and mica, and in the extreme stage of alteration even the primary quartz, have been replaced by topaz, tourmaline, secondary quartz and tinstone, to a less extent also by fluorspar, arsenopyrite, pyrite and magnetic pyrite, with some siderite. The proportion of each constituent in this mixture of these newly immigrated minerals varies. Those rocks richest in tourmaline are apt to be the poorest in tinstone. On the other hand, the selvages of the larger veins are said to consist sometimes of nothing but topaz (var. pycnite) and tinstone.

The true tin lodes, such as the North Valley lode and the Mount Bischoff lodes, contain quartz, iron spar, arsenopyrite, pyrite, tinstone, fluorspar, pyrophyllite and wolframite; only in rare cases do they also carry topaz. Their selvages are rich in sericite.

Neither the tin-bearing quartz porphyries, nor the true veins of the tin ore formation, are as important as the mass of residual débris produced from the veins by weathering. These residual deposits occasionally prove to be astonishingly rich, and are known as Faces.

White Face lies on the south slope of the mountain on both sides of an altered quartz porphyry dike. This deposit, like some parts of the two others, consists of angular or subangular fragments of the cassiterite-bearing topazized quartz porphyry, with associated topaz-quartz sand, rich in tinstone. The Slaughter-yard Face, further up the mountain, besides the materials just mentioned, also contains slate, together with much pyrite and the products of its decomposition, monazite and bismuth, all doubtless derived from a tin vein.

These talus gravels extend up to the mountain summit, often lying at an angle of 45°, and sometimes attaining a thickness of 21 m. (69 feet) and more. An older gravel deposit, with somewhat rolled material, has been found at the foot of the mountain.

The richest deposit, called Brown Face, lies on the east slope of the mountain, in the horseshoe-shaped basin enclosed by a ridge made by dikes

of porphyry. The deposit consists of tourmalinized slate and topazized quartz porphyry, with much limonite and iron ocher. It covers many acres and is in places 295 feet thick. The tin ore forms a fine crystalline sand readily washed out in some parts of the deposit, while in rare cases the ore occurred in the form of slabs of 10 or even 20 tons in weight, lying vein-like in the mass. The material has evidently resulted from the disintegration of a network of fissures and stringers of tin rock traversing and impregnating the slates and the quartz porphyries.

The Mount Bischoff tin deposits were discovered in 1871, as stream tin in Forth river. In 1873 the deposits of residual débris were first worked. The Mount Bischoff Tin Mining Company, operating on the three residual deposits just described, yielded an unusually large production. From its foundation to the close of 1902 it produced 60,946 tons of tin ore, with a content of 70% of tin in round numbers.

5. *The Tin-bearing Gravels of Banka and Billiton, Malay Archipelago.*

The Dutch East Indian Islands of Banka and Billiton contain one of the most important alluvial tin deposits of the globe.[1] Banka lies off the southeast coast of Sumatra, while Billiton lies somewhat farther east between Sumatra and Borneo. Both islands are mountainous. According to R. Verbeek they, together with the small islands in the intervening Gaspar strait, consist of steeply upturned beds of sandstone and slate, with numerous granite stocks. The age of the sediments is probably pre-Carboniferous. These rocks are altered near the granite by contact metamorphism, forming hornstones cut by numerous offshoots and dikes of granite.

The primary tin-vein and greisen deposits of these islands have already been mentioned (p. 213). The stanniferous gravel resulting from their destruction is of two kinds: (1) Residual gravels, "kulit gravels," or mountain tin gravels; (2) alluvial gravels, "kollong" or valley gravels. The former occur in the upper parts of the valleys and on the slopes near the outcrops of the lodes. The material has not been transported far, and in places contains huge lumps of cassiterite, larger than any found in the veins now worked, some of the lumps weighing over 1,000 kilograms.

A good idea of the occurrence of the stanniferous valley gravels is afforded by the accompanying longitudinal section through a deposit, after van Diest (Fig. 254). The cross-section shows: At the bottom, directly above the bedrock (called "kong") consisting of granite, hornstone, sandstone or schist, lies the "kaksa," a sand containing abundant granules of

[1] R. Verbeek: 'Geologische Beschrijving von Bangka en Billiton,' *Jaarboek* van het Mijnwezen in Nederlandsch Oost-Indie, 1897. Th. Posewitz: 'Die Zinninseln,' *Jahrb.* d. kgl. ungar. geol. Anstalt, Vol. VIII, 1886.

tinstone, the sand holding 2-4%, rarely up to 10% of tin. Besides cassiterite, it contains much quartz and lesser amounts of limonite, tourmaline, monazite, bauxite and curious obsidian balls and cones, which strikingly resemble the moldavites of Moravia.[1] Above the "kaksa" sand comes a cover 4-16 m. (13-53 ft.) thick of sand and clay. Nearer the point where the river empties into the sea the alluvial material is of course finer, clay and slime predominating, and the tin ore in the "kaksa" of such localities is very fine (tin ore flour). Some of the gravels also carry gold. The overlying gravels contain too small an amount of tin ore to pay for working.

Tin has been worked in Banka since 1710, mainly by Chinese companies, but lately under the supervision of European engineers. In 1896 Banka

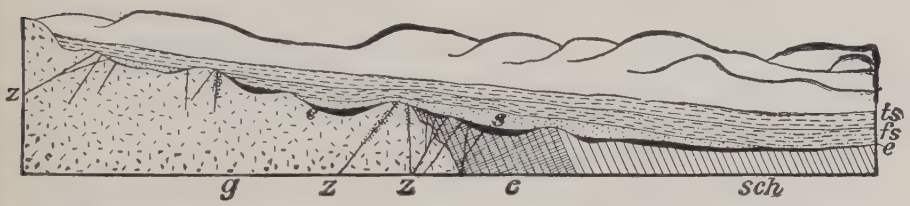


Fig. 254.—Ideal cross-section of a valley tin placer, a "Kollong" placer of Banka. (Van Diest.)

g, granite; sch, slate and quartzite; c, contact-metamorphic slate; z, tin veins; e, rich tin beds (kong) on bedrock; s, coarse sand; fs, fine sand in part earthy; ts, clay sand.

produced 148,122 pikuls, that is, in round numbers, 9,184 tons of tin, and Billiton about the same amount.

6. *The Tin-bearing Gravels of the Malay Peninsula and of Other Parts of Asia.*

There is an exceedingly close resemblance between the stanniferous gravels of Banka and Billiton and those of the Malay Peninsula, but the latter have a far greater production, furnishing over half of the world's supply of tin. The long mountain range extending along the southwest coast of the country contains a great number of stocks of granite intruded in shales and sandstones. Associated with the granites, or at any rate in their vicinity, there are tin veins and impregnation zones. The older rocks are in many cases uncomformably overlain by a granular limestone.

In almost all the numerous valleys descending from the mountain crest and draining granitic terranes, tin gravels are found, to wit:

[1] F. E. Suess: 'Die Herkunft der Moldavite und verwandter Gläser,' *Jahrb.* d. k. k. geol. Reichsanst., Vienna, 1900, Vol. L. With full bibliography.

On the west coast, especially in the States of Perak, Selangor and Sungei Ujong.

In the interior, in the States of Jelebu and Negri Sambilan.

On the east coast in the State of Pahang.

The most important deposits are in Perak and Selangor.

According to H. Louis, in the Malay Peninsula the lowest or pay gravel bed is 4-5 feet (1.2-1.5 m.) thick and covered by barren gravel to an average thickness of 15-20 ft. (4.5-6 m.), or rarely 80 ft. (24 m.). In an exceptional case observed at Sorakai Kinta, in Perak, over 80 feet of pay sand occurred under 20 feet of overburden. The average richness of the workable tin sands is about 1%, though it is exceptionally as much as 20% (Saiak Kinta, in Perak) in black tin.

A remarkable form of residual tin gravels is found, according to H. Louis,[1] at various points on both flanks of the Malayan mountain range, especially at Bukit Ebu, near Kernai, and at Dreda and Goa Tumbus, in Jalor. These are tinstone-bearing quartz sands, cemented by limonite looking like silicious bog iron ores. The cement seems to be derived from the decomposition of the iron pyrite and arsenopyrite of neighboring tin veins. The material which overlies decomposed granite is so hard it has to be crushed in order to wash the tinstone out of it. The amount of tin varies from 1% black tin, the lowest amount payable, to as much as 30%. A curious deposit at Goa Tumbus contains, besides tinstone, various oxidized lead ores, viz., anglesite, cerussite, pyromorphite and mimetesite, as a result of the weathering of both tin greisen and galena.

The rich tin deposits of the Malay Peninsula and the neighboring archipelago were known long before the Christian era. Perak, in particular, has produced tin for a long time, and as early as 1677 tin coins existed in Perak and Queda. The British colonies Singapore, Malacca and Penang, the so-called Straits Settlements, though producing no tin themselves, are the main ports of exportation for it. In 1897 the Malay States produced 45,632 tons of metallic tin.

In 1900 the total exportation of tin from Perak was 21,166 tons, and from Selangor 16,041 tons.

Tin gravels similar to those of the Malay Peninsula occur in the adjoining Siamese States, especially in Kedah and in certain parts of Burma.

7. *Tin-bearing Gravels of Mexico.*[2]

Among the alluvial tin deposits of Mexico, those of Tepezala in the State

[1] 'Ore Deposits,' 1896, pp. 597–603.

[2] José G. Aguilera: 'Geographical and Geological Distribution of the Mineral Deposits of Mexico,' *Trans.* Am. Inst. Min. Eng., Vol. XXII, 1902, p. 506.

of Aguas Calientes seem to be of special interest. Judging from the material in the Freiberg collection, the tinstone occurs in kidney-shaped masses formed of concentric shells and hence of concretionary origin. The nodules, which vary up to the size of a nut, are in part covered with a crust of hematite foils. Besides these concretions, which seemed to have been formed *in situ*, there are also found obtuse-angled, apparently rolled, fragments of a tinstone showing a centric structure.

8. *Tin-bearing Gravels of South Africa.*

In South Africa tin gravels are known in the Embabaan district in Swazieland, which are genetically connected with the tinstone-bearing pegmatite veins briefly described on page 217, and are worked in the "Ryan Tin Works." The tinstone is found in the alluvium of the valleys, which is 0.9-4.5 m. (2.9-14.7 ft.) thick, containing corundum, monazite, æschynite and magnetite,[1] associated with the tinstone.

(D) The Gold Gravels.

Gold Placers of the Southern United States.

The placer gravels of Georgia, Alabama and the Carolinas have long been worked. They are dredged in valley bottoms, whose gravels are fluviatile. At Dahlonega and elsewhere the outcrops of the gold veins and the residual gravels on the slopes near by are washed by hydraulic methods.

The Gold-bearing Gravels of California.

The auriferous gravels of California occur in a belt about 700 miles long that lies upon the lower western slopes of the Sierra Nevada. The

[1] A. T. Molengraaf· *Ann. Rep.* State Geol. of South African Republic, 1897.

[2] Important papers: Laur: 'Gisement et exploitation de l'or en Californie,' *Ann. d. Mines*, 1863, 6, III, p. 347. H. Credner: 'Beschreibung von Mineralvorkommen in N.-America,' *Berg u. Hütten. Zeit.*, 1866, p. 209. J. A. Phillips: 'On the Chemical Geology of the Gold Fields of California,' *Phil. Magaz.*, 1868, Vol. XXVI, p. 231. J. D. Whitney: 'The Auriferous Gravels of the Sierra Nevada of California,' Cambridge (Harvard College *Mem.*), 1879–1880. J. Leconte: 'The Old River Beds of California,' *Amer. Journ. Sc.*, 1880, iii., XIX, p. 176. Ross E. Browne: 'The Ancient River Beds of the Forest Hill Divide,' 10th *Ann. Rep.* Cal. State Mineralogist, 1890, pp. 437–440. H. W. Turner: 'Auriferous Gravels of the Sierra Nevada,' Amer. Geol., 1885, p. 372. A. C. Lawson: 'The Post-Pliocene Diastrophism of the Coast of Southern California,' *Bull.* Dep. of Geol. Univ. of Calif., 1893, Vol. I, p. 115. W. Lindgren: 'Two Neocene Rivers of California,' *Bull.* Geol. Soc. of Am., 1893, Vol. IV., p. 257. 'Geological Atlas of the U. S. Geol. Survey,' Sacramento and Placerville *Folios*, 1894. W. Lindgren and F. H. Knowlton: 'Age of the Auriferous Gravels of the Sierra Nevada,' *Journ.* Geol., 1896, Vol. IV, p. 881. J. F. Kemp: 'Ore Deposits,' 1900, pp. 353–362.

general geologic structure of this range and its primary gold deposits have already been described.

Three different kinds of auriferous gravel deposits may be distinguished in California. The grouping, being based on the mode of working, brings together formations not quite of the same geologic age.

(a) Alluvial and Pleistocene gravels on the floor of recent river valleys.

(b) Bench gravels found on the valley terraces of the middle part of the stream valleys, not very far up above the present channel; the deposits are mostly worked by the hydraulic methods.

(c) Gravels of Eocene to Pliocene age on plateaus and high valley terraces, mainly exploited by underground work ("deep gravel" mines).

(a) Alluvial and Pleistocene Auriferous Gravels.

The alluvial and Pleistocene gravels (shallow placers) of California generally consist of rather coarse, rolled material, especially of the harder drift of the older gravels, here occupying its third place of deposition. The gold was sometimes found in such gravels in rather coarse nuggets, but occurred mostly in fine grains and minute flakes. In contrast with the older Tertiary gravels, the gold is very irregularly distributed and is accompanied by magnetite, less commonly by zircon, garnet and occasionally a little platinum and osmiridum. These placer deposits are confined to the bottoms of the present valleys and are mainly of fluviatile, but in part of littoral origin. They have been worked since 1849, and though very rich, were practically exhausted by 1860. This early work was done by very primitive methods, the ground being often gone over several times.

(b) The Late Tertiary Auriferous Gravels (Bench Gravels).

These deposits are distinguished from the preceding group solely by their higher elevation above the present streams. They form terraces midway up the valley slope, their elevation above the streams making it possible to work them by hydraulic methods. By this work great quantities of gravel and sand have been washed down the valleys, ruining large tracts of fertile bottom land. This is now regulated by a national débris law.

These two classes of gold-bearing gravels are also found in other parts of the United States, as, for example, according to Kemp, at Santa Fé in New Mexico, in California gulch, near Leadville, at Fairplay and in San Miguel county, Colorado, in the Sweetwater district in Wyoming, at Pioneer, Last Chance and Prickly Pear gulches at Helena, Montana, in the

Black Hills of Dakota, on Snake river and elsewhere in southern Idaho, and at several points in Washington and Oregon.

(c) The Tertiary Gold Gravels.

The Tertiary auriferous gravel deposits are remnants of old river courses, preserved from destruction and denudation, usually by lava streams. They grade into littoral terrace deposits and were formed in various epochs of the Tertiary period. The detailed mapping of these deposits by the United States Geological Survey gives a record from which it is easy to show the course of these ancient valleys, some of which run parallel to the present valleys, while others cross them at right angles. These formations extend along the slopes of the Sierra in a zone 250 miles long and reaching an elevation of 2,100 m. (7,000 feet) above the sea. Their thickness is often very great, as, for example, at Mount Columbia, where it is 180 m. (590

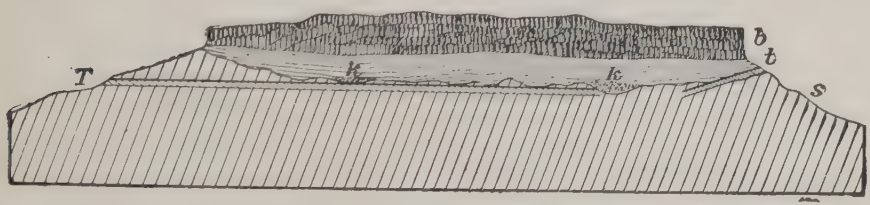


Fig. 255.—Section through Table mountain, California. (Whitney.)
s, older schists; k, channels, that is to say, gravel-filled grooves on the schist; t, pipe clay and sand; b, basalt; t, tunnels (Buckeye tunnel).

ft.), but generally it is very much less. They cover areas 45-300 m. (150-1,000 ft.) broad. The bedrock on which they rest ordinarily shows distinctly the form of a trough, with one or more deeper channels, as shown in the section, Fig. 255. The flanks of these old valleys in the rock floor are called "rims," the floor itself is called the "bedrock." In the tilted schists, the channels as a rule cling to the softer strata.

The material deposited in these ancient river beds consists of shingle, gravel, sand, clay (pipe clay), volcanic tuff and solid lava sheets of basaltic, rhyolitic or andesitic composition. The drift of the coarser layers consists principally of quartz, in part of metamorphic schists and in certain late Tertiary occurrences also of volcanic rocks. The drift is frequently cemented by a siliceous matrix. The very common occurrence of silicified wood proves the circulation of siliceous waters. Bones and teeth of extinct Tertiary vertebrates have been found in the gravels, while the clays contain leaf impressions of late Tertiary species. The auriferous gravels

contain vertebrate remains, together with human remains and stone bowls and implements of prehistoric man, at Table mountain in Tuolumne county, California.

The volcanic tuffs occasionally found intercalated between the fluviatile strata are conceived to be streams of mud that flowed down into the old valleys after great eruptions of ashes in the mountains.

These old river courses have in many cases been affected by subsequent dislocations. Not only has the entire mountain region risen as compared with the coastal region since the formation of these auriferous gravels, as shown by LeConte and others, but the gravel deposits themselves are traversed by fissures and displaced. Such a case is illustrated by Fig. 251. Sometimes eruptive dikes are intruded along fault planes in the gravels. It is said that crumpling of the fluviatile strata has also been observed.

The richest gravels lie next to the bedrock, the gold being usually concentrated in the old channels cut in the solid bedrock. The auriferous pyrite found in these basal ("blue") gravels will be discussed further on.

Recent detailed mapping and study of the Tertiary gravels shows that they may be divided, according to their age, into the following stages:

From the Eocene a few doubtful occurrences are known. The greatest number belong to the Miocene, while the gravels which contain andesite tuffs and lavas are referred to the Pliocene. In Amador and Calaveras counties these fluviatile Pliocene strata pass into marine gravels. These represent deposits in the great gulf which in Pliocene time filled the central valley of California. These marine gravels occur from 500 to 700 feet above the sea level.

The exact age of the beds lying immediately below the basalt sheets, from which the prehistoric remains have been obtained, is as yet doubtful, but they probably belong to the Pleistocene.

2. *The Gold Placers of the Yukon and Other Districts in Alaska.*

The discovery of the rich gold placers in the Yukon district, especially on the Klondike, a tributary of the Yukon, has directed widespread attention to this remote region.

The Yukon, the largest river of Alaska, is formed by the union of its several forks, in Canadian territory, at about 60° north latitude; it main-

[1] Important papers: G. M. Dawson: 'Report on the Yukon District in 1887,' Geol. Surv. of Canada, 1887–88, Vol. III, part B. J. E. Spurr: 'Geology of the Yukon Gold District, Alaska.' 18th *Ann. Rep.* U. S. Geol. Survey, 1898, part III. S. F. Emmons: 'Map of Alaska with descriptive text containing sketches of the Geography, Geology and Gold Deposits,' U. S. Geol. Survey, 1898. O. Nordenskjöld: 'En Expedition till Klondike och Yukonterritoriet,' Ymer, 1899, part 1. J. B. Tyrrell: 'Glacial Phenomena in the Canadian Yukon District,' *Bull.* Geol. Soc. Amer., 1899, Vol. X, p. 193. F. Andersson: 'Das Klondike-Goldfeld,' etc. Essener *Glückauf*, 1901, No. 6, 7.

tains a northwesterly course up to the Arctic circle; then turns southwest and empties into Norton Sound, a part of Behring Sea. The richest placers are in Canadian territory in an area 21 km. (12.6 miles) broad and 43 km. (25.8 miles) long, lying between the Klondike and Indian rivers, both entering the upper Yukon from the east.

Farther down stream on United States territory the rich placers of the Forty Mile district and of Birch Creek occur in the valleys of these lateral branches of the Yukon.

In these regions the country rock is formed of crystalline schists, partly mica schists, hornblende schists, crystalline limestones and diabase tuffs, but principally of Paleozoic slates and quartzite schists. All these schists are intruded by granites, and the most of them are cut by pyritic gold quartz veins and some of them by veins of pegmatite.

The gold-bearing gravels rest as a rule directly on a schist bedrock, while occasionally a clay stratum forms the "false bedrock." Usually the schist bedrock is much decomposed and holds gold caught in its cracks and fissures. The workable gravel is usually confined to a layer 0.6 m. (1.9 ft.) thick, which exceptionally reaches a thickness of 3 m. (10 ft.) above bedrock. The cover of overlying barren gravel is usually 2.5-3 m. (8-10 ft.), but may amount to as high as 7.5 m. (24.5 ft.) in thickness. The gravels consist of large and generally flat slate fragments and slightly rolled quartz pebbles, mingled with sand. The gold occurs in part as rather coarse particles, occasionally still showing vein quartz. The accompanying heavy minerals are galena, magnetite, brown hematite, hornblende and garnet.

In the Klondike area, between the Klondike and Indian rivers, which has become the most famous, the prevailing bedrock is a mica schist, whose quartz stringers were in some cases found to be gold-bearing. The gold-bearing deposits are divided into valley gravels, lower terrace gravels and upper terrace gravels. The last named consists of a brown, non-auriferous upper layer and a whitish, quartz-bearing, auriferous lower layer. This layer, known there as "white gravel channel," is the oldest gravel formation of the region. It consists of the proportion of 75-80% of quartz and mica schist pebbles, imbedded in quartz sand and containing mica scales.

The Eldorado deposits are the best known of the valley gravels. The lowest 39 claims of this tract contained extraordinary amounts of coarse gold. This gold was of very low fineness (only 750). The flake gold of the lower Bonanza valley, on the contrary, carries less silver.

Among the upper terrace gravels those of Gold Hill at the union of the two valleys just named furnished the most gold. The gold there increases in amount from the edge of the terrace inward. The "white gravel channel" is there up to 25 m. (81 ft.) thick, and holds scales and rounded nug-

gets of gold. On the contrary, on the upper terrace of French hill, at the junction of French Valley with Eldorado Valley, sharp-edged or angular nuggets are found, often studded with crystals.

As the gravel beds of these Arctic districts are for the most part in a frozen condition from one end of the year to the other, they have first to be thawed out in development work, and the gold-washing proper is limited to the brief summer season.

The first gold find of the Yukon river region was made in 1871 far from the Klondike, on Dease lake, near the source of Stikine river, in British Columbia, where placer mining was actively continued until 1887. Subsequently the gravels on Birch creek and in the Forty Mile district were dis-

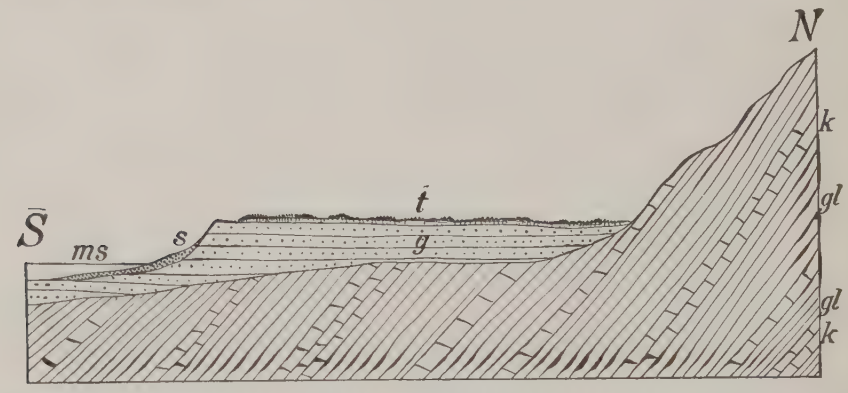


Fig. 256. -Cross-section of the beach placers and bedrock at Cape Nome, Alaska. (Schrader and Brooks.)

gl, mica schist and gneiss; k, limestone; t, turf and soil of the tundra; g, old gravel, sand and clay; s, gold-bearing sand and gravel; ms, sea-level.

covered, and it was not until the autumn of 1896 that those of the Klondike region proper were found. The value of the gold production of the Yukon district in 1900 was about $18,000,000. The total value of the available placer gold stored there by nature was estimated by McConnell at $95,000,000.

3. *The Gold Gravels of the Cape Nome District.*[1]

In recent years the gold deposits of Cape Nome in Norton Sound, Alaska Territory, discovered in the autumn of 1898 and worked since the summer of 1899, have aroused considerable discussion. They are located in 64.4° north latitude, in a very bleak, inhospitable region on the shore of

[1] Weber: 'Die Goldlagerstätten des Cape Nome Gebietes,' *Zeit. f. Prak. Geol.*, 1900, pp. 133–136.

Behring Sea and in the valleys of Snake and Nome rivers, which debouch there. On the seashore they consist of a stratum of reddish, gold-bearing sand, up to 10 cm. (4 inches) thick, thinly covered with gravel, and extending along the shore for a great distance, with an average breadth of 22 m. (72 ft.), while in the valleys the gold-bearing sands lie under the mossy peat which covers the tundra, the sand being separated from the bedrock by a clayey layer poor in gold. The valley gravels contain much garnet and magnetite, with here and there some platinum and cinnabar.

We give a characteristic cross-section of the beach gravels in Fig. 256, after Schrader and Brooks.[1] In the summer of 1899 three men washed from the beach sand about $470 worth of gold per man from Aug. 19 to 25. The new town of Nome City quickly sprang up, and by the end of the summer of 1899 as many as 5,000 gold-seekers had flocked there.

Gold gravels have also been discovered on the east coast of Siberia, opposite Cape Nome.

4. *Gold Gravel Areas in South America.*

The most interesting districts of gold-bearing gravels in South America are those of Surinam (Dutch Guiana), British Guiana and Venezuela.

With the exception of a narrow coastal zone of younger sediments, the country rock of forest-covered Surinam[2] consists of a complex of massive and schistose crystalline rocks, especially granites, gneisses, mica schists, amphibolites and quartzites, in which gabbros, diabases and diorites are intercalated. Several of the northward-flowing rivers, particularly the Surinam, show deposits of gold-bearing gravels. According to G. DuBois most of this gold is derived from gold-bearing diabase masses, only a tenth of the placers receiving their precious metal from eroded gold lodes, as, for example, the de Jong placer and the Guyana Goud placer. Most of the placers could receive it only from gold-bearing diabases. This derivation is indicated by the close association between placer gravels and diabases. Moreover, in many instances the ordinary residual product of the weathering of these rocks has been profitably washed for gold. The higher gravels on the slopes of the diabase mountains contain less gold than those lower down.

The concentration of the gold in the laterite is illustrated by Du Bois by the following data: At the Victoria placer, slightly decomposed dia-

[1] 'Preliminary Report on the Cape Nome Gold Region, Alaska,' U. S. Geol. Survey, Washington, 1900.

[2] G. C. Du Bois: 'Geol. bergm. Skizzen aus Surinam,' Freiberg, 1901. Also 'Beitr. zur K. der Surinamischen Laterit und Schutzrindenbildungen, Tschermak's *Min., u. petro. Mitth.*, 1903, Vol. XXII, p. 39. W. C. H. Staring: 'Jetsover de Geol. Gisteldheit van Suriname.' Alg. Konst en Letter-Bode, 1884. K. Martin: 'Bericht über eine Reise nach Niederl. West Indien,' Leiden, 1888.

base showed 0.2-0.6 grams per ton, while the decomposed rock *in situ* showed 3 to 10 grams per ton. The greatest enrichment in this sharp residual laterite gravel is found a little above the contact of the laterite débris with the deep laterite underlying it as a bedrock.

The placer gold is usually in grains, often as fine as dust. Quite rarely large nuggets are found, like that found in 1896 on de Freitas placer, weighing 5.876 kilograms. In the Victoria placer and elsewhere the so-called black gold is found, that is to say, lumps with a shining black crust of ferrous oxide.

The discovery of the gold placers occurred in 1874. The annual gold production of all Surinam reached its maximum in 1891, with 1,236.919 kilograms. In 1899 it was 872.249 kilograms.

The most important gold placer deposit of British Guiana is that of Omai, on the left bank of the Essequibo river, 120 miles from Georgetown. According to E. E. Lungwitz,[1] the gold varies from particles as fine as dust up to nuggets weighing 1,057 grams and it is always accompanied by considerable auriferous quartz. According to the same author the gold is partly derived from a huge vein of feebly auriferous aplite, a fine-grained dike-granite, in which it is associated with cupriferous iron pyrite, while another part is derived from disintegrated conglomerates and sandstones. The manner in which Lungwitz imagines the transportation of this placer gold to have taken place is discussed later.

In Venezuela the gold placers on the Yuruari river in the highlands of Upata, south of the Orinoco, discovered in 1849, led to the subsequent opening of the famous primary deposit near Callao (see page 300).

The placer or derivative, as well as the primary gold deposits of French Guiana, are treated in detail by E. D. Levat.[2]

According to this author the gold deposits of that region are principally found at the contact between gneiss or crystalline schists and intrusions of igneous rocks, more especially where masses of diorite and diabase are found in the schist. These rocks predominate, for example, in the bedrock of the placers of St. Elie, Dieu Merci, Elisée, Pas-trop-tôt and Awa. In most cases gold has also been found in several neighboring valleys, radiating from a diorite or diabase mass of this kind.

These rocks possess a primary gold and silver content, the gold being either free (as proven even in perfectly fresh, undecomposed samples) or

[1] E. E. Lungwitz: 'Ueber die regionalen Veränderungen der Goldlagerstätten, Diss. Rostock.' Leipzig, 1899. Same author: 'Die Goldseifen von Britisch-Guiana,' *Zeit. f. Prak. Geol.*, 1900, pp. 213–218. J. B. Harrison and H. J. Perkins: '*Rep.* on the North Western Distr. of Brit. Guiana,' Georgetown, 1897–98.

[2] E. D. Levat: 'The Gold Fields of French Guiana,' 'The Mineral Industry,' New York, 1899, Vol. VII. Also 'Guide Pratique pour la Recherche, etc., de l'Or en Guyane Française,' Paris, 1898.

contained in the pyrite, which sometimes constitutes as much as 5% of the rock. The following table, after Levat, shows amount of gold in unaltered igneous rocks of French Guiana:

	FeS_2 %	Gold Grams per 1,000 kg.	Silver Grams per 1,000 kg.
Diorite from Roche creek	5.2	2.0	6.0
Diorite from Pichevin creek	4.1	1.5	2.0
Diorite from Maripa with visible free gold	0.5	24.0	4.0
Amphibolite ("Grison") from Telegraph Mountain in Cayenne	1.4	0.24	0.02

Compare this with what has been said on page 16 on the primary native gold found in diabases and diorites.

These "greenstones" are the source of the gold found in certain cemented residual gravels called "roches à ravets" (cockroach rock, so called because of the porous and cavernous nature of the rock). These rocks are lateritic limonites, resembling bog iron ore and being a product of weathering. They do not form horizontal strata in the valleys, but spread over both hill and valley as a universal mantle.

The following analyses by Levat confirm this theory of the origin of this concretionary ironstone from diorites or diabases:

	Fe_2O_3	Al_2O_3	SiO_2	CaO	P_2O_5	MgO	H_2O
1. Sample I from Maripa	54.70	12.10	8.55	5.50	0.67	6.10	7.80
2. Sample II from Maripa	59.40	14.80	9.50	6.80	0.02	5.40	9.10
3. Sample from Roche creek at Awa	60.35	14.10	7.40	.....	.....	.....	14.10
4. Sample from Pichevin creek at Awa	59.40	14.50	6.50	4.80	1.02	3.10	10.10
5. Sample from Central Settlement at Awa	58.25	13.15	8.10	.....	.....	.....	.....

These gossan rocks contain free gold, always alloyed with silver, as is the case with the primary gold in the diorite and diabase. The amount varies from 0 to 18.5 grams per ton and in exceptional cases as much as 73 grams of gold per ton, with 16 and 20 grams of silver per ton, the fineness of the gold being only 700-850 thousandths.

Besides these residual deposits, true river placers are also known in which the barren gravel is mainly quartz, the deposits resting on a bed-rock decomposed into clay. Immediately above this clay is their richest layer, having a thickness of 5-10 cm. (2-4 inches). Such placers occur, for example, on the Appronague, Sinnamary and Mana rivers. The gold

may be derived from quartz veins carrying pyrite and some arsenopyrite, bedded veins which traverse the crystalline schists at several points and give rise to cataracts where they cross the river valleys Some of these veins, like that of Adieu Vat, proved to be workable.

In Chili the gold placers at Punta Arenas and in northern Tierra del Fuego were reported on by R. Pöhlmann.[1] Their parent rock is stated by him to be a mica schist carrying lenses of gold-bearing quartz. The material has been transported by glaciers and spread out by rivers.

5. *The Gold Placers in the Ural.*

The middle and southern sections of the Ural mountains, especially in the vicinity of Bogoslovsk, Nizhne Tagilsk, Berezovsk, Miask and Orenburg are rich in gold placers[2], whose geologic relations are described by A. Karpinsky in an official report made after a detailed survey.

The gold placers of the Ural form stratified deposits 1½ to 3 ft. in thickness, seldom as much as 13.12 ft. They extend usually a distance of 20-40 m. (65-131 ft.), but sometimes to 200-500 m. (656-1640 ft.). Only in very exceptional cases are placers found 4.5-12 km. (2.7-7 miles) long, as in the gravels of Peschanka in the Bogoslovsk district. Their breadth is sometimes slight, 2-4 m. (6.5-13 ft.), usually about 20-40 m. (65-131 ft.) exceptionally even 100 m. (328 ft.) and more. Sometimes the gold-bearing sediments lie directly under the sod, but they are commonly found under a cover of barren gravel, sand and clay, 0.5-4 m. (1.6-3 ft.) or even 20 m. (65 ft.) thick. The cover is called "turfa," because, in the case of the first gravels worked, peat (German *torf*) actually covered the gravels, and since then this German word has been used for every kind of cover. The gold-bearing sands and gravels almost always rest directly on bedrock ("plotik"); only in rare cases are they separated from it by layers of barren gravel or sand.

Most of the placers lie on the east slope of the Ural mountains, in the broad valley flats of the middle course of the present rivers and usually below the present level of the rivers. As shown by the remains of *Elephas primigenius, Rhinoceros tichorhinus* and other Pleistocene animals found in the gold-bearing strata, the deposits belong to the Pleistocene, and represent a period of active valley-filling, which gave rise to the many lakes

[1] R. Pöhlmann: 'Die Goldseifen bei Punta Arenas und im nördl. Feuerland,' *Verh.* d. Deutsch. wissensch. Ver. in Santiago (Chile), Vol. IV, pp. 307–318.

[2] A. Karpinsky: 'Sur les sables aurifères' (in Russian), 1840. R. Helmhacker: 'Der Goldbergbau der Umgebung von Berezovsk,' *Berg u. Hütten Zeit.*, 1892, p. 45. F. Posepny: 'Die Golddistricte von Berezov und Mias am Ural,' *Archiv* f. prakt. Geol. zu Freiberg, 1895, Vol. II, pp. 499–598.

and swamps of this part of the mountains, some of which are also filled with gold-bearing detritus. Thus, for example, gold-bearing sediments are known in Lake Ilmen.

The gold occurs as minute granules or scales, nuggets being rarely seen. The largest nugget known weighed about 36 kilograms (80 lb.) and came from the Tsarevo-Alexandrovsky placer of the Miask district. The distribution of the gold often varies. However, the rules given on page 619 generally apply. The amount of gold in the Ural gravels usually varies between 0.57 and 2.6 grams per ton. Below 0.57 grams, washing no longer pays. However, where sufficient water is present, and the conditions are otherwise favorable, this lower limit is closely approached, as for example at Bogoslovsk, where a placer deposit 2 m. thick, with an average content of no more than 0.6 grams of gold per ton, has been exploited, though it lies under a barren cover 2.5 m. (8.2 ft.) thick. In exceptional cases pockets of much richer sands were encountered in the placers, some with a content of 16 kilograms of gold per ton.

The gold is accompanied in all the placers by magnetite, more rarely by hematite, menaccanite, chromite, platinum, cinnabar, garnet, zircon, cyanite and diamond.

Most of the gravels lie on the crystalline schists, and some of the schists act on the floor of the placer deposits as gold riffles.

The primary gold deposits of the Ural, from which the gravels are derived as a disintegration product, are described on pages 303, 304 and 310,

While the gold veins of the Ural are said to have been discovered as early as 1745, placer gold did not attract attention until 1814, when it was mined at Berezovsk. It seems, however, that the prehistoric Chudes washed gold in these mountains, for in the Chude tombs, according to Posepny, gold bracelets were found having composition identical with the placer gold of the locality.

In 1899, the Ural produced 10,448 kilograms of gold, to wit, Perm government 6,015.34 kg., Orenburg 4,420.7 kg., Ufa 12.3 kilograms.

6. *The Gold Placers of Siberia.*[1]

Both West and East Siberia are rich in gold placers. In West Siberia, within the Tomsk mining district, placers are found in the barren steppe extending east of the Ural around Tobolsk-Akmolinsk and in the Altai region in the district around Semipalatinsk-Semiryechinsk. They are generally poor. In the regions adjoining the Chinese boundary, placer

[1] M. W. Gribassowy: 'Der Goldbergbau in Sibirien,' Berlin, 1896. E. Levat: 'L'or en Sibérie orientale,' Vol. II, Paris, 1898. René de Batz: 'The Auriferous Deposits of Siberia with Mining Map of Siberia,' *Trans.* Am. Inst. Min. Eng., 1899, Vol. XXVIII, p. 452.

deposits are worked which hold but 0.16-0.21 grams and rarely with but 0.32-0.40 grams of gold per ton of sand. At some points the abundance of water and the great thickness of gold-bearing strata, rising as high as 10 m. (32.8 ft.), make it profitable to work gravels containing but 0.108 grams per ton of sand. In the Altai region, sandstones and clay slates together with metamorphic granitic and dioritic masses form the bedrock. Farther north, too, in the forest area of the Tomsk mining district, in the Marrinsk, Biisk, and Kuznetsk, active placer mining is carried on. Gold veins have also been opened at Dimitrievsk, Voshresensk, Proroko-Ilinsk, etc.

In Central Siberia the very rich placers of the Yenisee basin are now mostly exhausted; others occur in the mining districts of Yenisee North and Yenisee South, as well as Krasnoyarsk and Kainsk. The gold-bearing gravels varied between 1.4 and 2.8 m. (4.6-9 ft.) in thickness and in exceptional cases reached as much as 2.8 m. (9 ft.). The pay gravel is covered by 0.7-10.65 m. (2-35 ft.) of barren material. In 1882, lode mining was begun here.

The placers of East Siberia occur in the Irkutsk mining district, where they are distributed over a vast area. On the whole they are richer than those of West Siberia. The following are the main regions: The Lena Basin, the Nerchinsk district in Transbaikalia, on the head-waters of the Amur, Shilka and Argun, and the Amur basin proper, together with the coast region south of the mouth of that stream.

The auriferous alluvial deposits of the Lena region lie on the northwest slope of the Yablonoi mountains, especially along the Olekma and Vitim rivers and their tributaries. About Olekma the placers average 2.7-4.3 grams and in the vicinity of Vitim 7.8-12.8 grams, rising in exceptional cases to 14.3 grams per ton. The gold is rather coarse grained, but occurs only rarely in nuggets. Occasionally two or even three gold-bearing layers occur one above the other. Like the Klondike region, the entire bed of workable material is perpetually frozen.

In Transbaikalia, the principal placer deposits are in the Chita, Aksha and Nerchinsk regions and at Bargusinsk and Upper Udinsk in the western part of that country.

The gold gravels of the Amur region form four groups on the left tributaries of the river: (1) Between Amur and Seya, above Blagovyeshchensk; (2) on the tributaries of the Gilyui and the Bryanta; (3) on the Selenga; (4) on the upper course of Imana river. Gold veins are also worked there.

In the coast area, the richest placers are found in the river valley of the Amguna, which empties into the Amur. Besides the fluviatile placers

of these districts, the auriferous marine sands of Askold island near Vladivostok are worked in some places by dredges, which excavate and treat sand of the sea-bottom.

Gold mining in Siberia did not begin until the 19th century. In 1831, gold mining was begun in the Altai, in 1832 in the vicinity of Nerchinsk, in 1836 on the Briyussa in the Yenisee area, in 1849 on the Lena, in 1866 in the coast region, in 1868 in the Amur basin proper.

According to M. W. Gribassovy, West Siberia produced in 1893 2,915.64 kg.; East Siberia, 29,827.98 kg. of gold; all Russia in the same year, 44,733.78 kilograms.

7. *Gold Placers in India.*

A second Asiatic country containing gold placers is India, including the Himalayan States. According to Phillips-Louis' summary[1], the placer districts of nearer India all lie in zones of metamorphic schist, whereas in Ladak the alluvial gold comes from quartz lodes traversing Carboniferous strata; in Candahar its primary source is in Cretaceous rocks; and finally along the Himalaya, from Afghanistan to the frontiers of Assam and Burma, as well as in the Salt Range, the alluvial gold is derived from Tertiary sediments, into which it was carried from eroded metamorphic schists.

Among the more important occurrences may be mentioned those of Wynaad, a mountain land between the coast of Malabar and the Nilgherry highlands in southern India. At this place the alluvial gold is derived from pyritous quartz veins, traversing granite-gneiss and various crystalline schists. The veins themselves have also been mined.

Important gold placers formerly existed in the province of Mysore, but they, too, now seem to be abandoned. Vein mining still flourishes, however, especially in the Kolar goldfield east of Bangalore, where pyritous gold quartz veins are found in gneiss and hornblende gneiss.

Gold is also washed in the southern part of the province of Chota Nagpur, where *rhizoda* are found in the crystalline schist formation called "Darutar series."

Gold has also been obtained from the Irawaddy and some of its tributaries in British Burma.

8. *Gold Placers of Australia.*

Gold placers are known to exist in practically all the Australian colonies. Some of them have yielded and are still yielding a large output.

[1] J. A. Phillips and H. Louis: 'A Treatise on Ore Deposits,' London, 1896, pp. 560–576.

Victoria, besides its alluvial placers, possesses others of Miocene, Pliocene and Pleistocene age, some of them buried under basalt sheets, like those of California[1]. Of all these the most important are thin alluvial placer deposits of Ballarat, Beechworth, Sandhurst, Maryborough, Castlemain, Ararat and Gippsland which yielded enormous amounts in the early days after their discovery and afforded many large nuggets.[2]

The most important Tertiary 'deep leads' of Victoria are at Ballarat. In several mines a succession of four thick basalt sheets, separated by beds of clay, had to be pierced by shafts before the gold-bearing gravels and bedrock were reached. The clays which alternate with gold-bearing sands often hold well preserved tree-trunks and leaf-im-

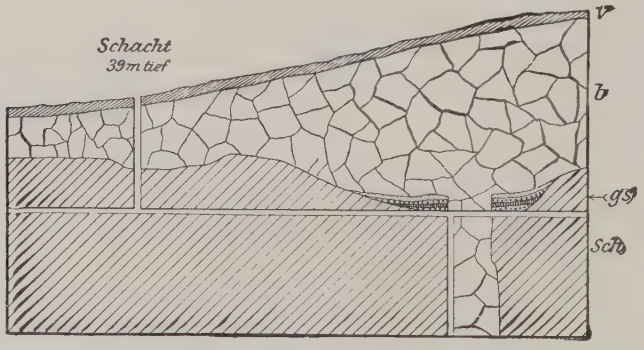


Fig. 257.—Section through Wombat Hill near Daylesford. (H. Louis.)
sch, slates; gs, gold-bearing sand and gravel; b, basalt; v weathered layer.

pressions, or even streaks of lignitic brown coal. In some instances the mine workings have disclosed the necks or dikes of basalt that fed the lava flows and intrusive sheets, as is shown in the profile of the mine at Wombat Hill, reproduced in Fig. 257.

Both the alluvial and Tertiary placers of Victoria contain cement deposits, which closely resemble the ordinary pay gravels, but are firmly cemented by a matrix of limonite. These deposits usually rest directly on bedrock.

It is noteworthy that many of the gold placers of Victoria carry cassiterite.

In 1894, when placer mining in the colony was still actively carried

[1] T. A. Rickard: 'Alluvial Deposits of Western Australia,' *Trans.* Am. Inst. Min. Eng. October, 1898, p. 40.

[2] R. Brough Smyth: 'Gold Fields and Mineral Districts of Victoria,' Melbourne, 1869. Phillips-Louis: 'Ore Deposits,' 1896, p. 619. 'Deep Alluvial Mining in Victoria,' F. Danvers Power, *The Engineering and Mining Journal*, 1904, Vol. LXXVIII, p. 509.

on, the total gold output from them amounted to 7,908.9 kilograms, but the production of placer gold has steadily declined, since the average amount of gold in the pay gravel (wash dirt) was about 2 grams per ton in 1894. In the so-called cements it was about 6 grams per ton.

Similar geologic conditions prevail in the gold placers of New South Wales, which in 1894 produced some 2,215 kilograms (71,213 oz.) of placer gold, and in Queensland, which in the same year produced 806.6 kilograms of gravel gold. Gold placers exist also in South Australia, and, as has been found during the last decade, in West Australia. The dry table land of West Australia contains peculiar residual gold gravels, which deserve a somewhat more detailed mention.

From a detailed description accompanied by a full collection sent to the writer by A. Gmehling, it is known that at Kanowna and in the Twenty-five Mile district the older rocks near the gold veins are covered by a mantle of sandstone and agglomerate. These so-called rich cements are rich in kaolin and often in iron, and are worked for gold.

The quartz grains of the sandstone specimens sent to the writer are seen under the microscope to be remarkably sharp-edged splinters, so that in 1898, in a letter to A. Gmehling and in lectures after that, the writer expressed the conjecture that the cements may be eolian formations, developed during the weathering of the older lodes under the influence of the desert conditions of those regions, which with its great contrasts of temperature between day and night promotes the cracking and splintering of the rock. It is a satisfaction to know that this conjecture has been completely confirmed by T. A. Rickard[1] on the basis of his very detailed investigations of the mines.

This investigator studied the Kintore cement deposit, 23 miles northwest of Coolgardie, and another at Kanowna, 25 miles northeast of Kalgoorlie, both of which he regards as débris of weathering, produced in a large measure by the great differences of temperature between day and night and by the strong winds of this dry, almost rainless country. The Kintore cements are derived from the gold quartz veins of the Sugar Loaf mine, which extend past one end of the deposit and in close proximity to it; the source of the Kanowna cements was the White Feather gold vein, outcropping in the immediate vicinity. At Kintore, according to Rickard, the surface of the granite bedrock is marked by pot-holes 2 to 3 ft. across. The rock is overlain first by the gold-bearing sandy cements, averaging 2½ to 5 ft., next by barren "sand rock" (up to 2 ft.), and finally by a bed of kaolin a few inches to a foot in thickness, the surface being covered with

[1] T. A. Rickard: 'The Alluvial Deposits of Western Australia,' *Trans.* Am. Inst. Min. Eng., 1899, Vol. XXVIII, p. 480.

sand and dust[1]. A few narrow clay bands are intercalated in the sandy masses. At Kanowna, on the contrary, the bedrock is a strongly decomposed diorite. In this rock, a shallow depression, that is 700 ft. by 105 ft., holds at the top a few inches to 2½ ft. of sandy loam worked by the dry blowers, then a layer of detritus (wash), consisting of fragments of ironstone and quartz, imbedded in clay and reaching to a maximum of 25 ft. below the surface. This overlies the cement, itself a bed 6 inches to 5 feet thick, composed of quartz in greenish clay. Near the rim of the trough the quartz occurs in larger, more angular pieces. The gold contents are irregular, but probably averaged about one ounce per ton (31 grams per met. ton). Only the richer parts were at first worked, but later the remnants, carrying $3.05 per ton, were extracted and stamped.

The island of Tasmania also produced placer gold until quite recently, the output for 1894 being 175.2 kilograms.

In New Zealand Tertiary gold placers occur at high elevations, while the recent ones are fluviatile or marine. The elevated placers consist in part of loose gravel and sand, so that they may be worked by the hydraulic method; others are firmly cemented as in the Otago goldfield at Blue Spur. The recent fluviatile placers are almost all situated on Middle Island; both they and the gold-bearing sea-sands are worked by a number of steam dredges. The beach sands are constantly regenerated by the comminuting activity of the surf.

9. *African Gold Placers.*

The gold placers worked at various points by the natives of the Gold Coast of Africa are of slight importance compared to the primary gold vein deposits of that country (see page 519).

Important placer areas occur, however, in the Lydenburg district in the Transvaal especially in Pilgrim's creek and in Blyde valley, which were worked as early as 1873. A residual gold placer occurs at Duivels Kantoor, in the Kaap goldfield of the same colony, where pyrite crystals changed into brown hematite and crystalline gold are found in a weathered débris consisting of still angular fragments of quartz and various rocks. In 1894 the deposit produced 18.6 kilograms of gold. A nugget weighing 1.6 kilograms from that locality was exhibited in Paris in 1900.

10. *Gold Placers of Europe.*

The numerous gold placers of Europe are all now totally exhausted, or yield such minute returns that they are no longer of the least economic importance, though many of them may claim scientific interest.

[1] T. A. Rickard: *Op. cit.*, p. 35.

Among the best known are the gold-bearing alluvial deposits of the Rhine, which were worked by a few gold-washers as late as the forties of the 19th century, between Rheinau, near Rastatt, and Daxlanden, near Karlsruhe. The gold was found concentrated in certain sandbanks, called "gold grounds." According to A. Daubrée[1], gold is also found in older terraces up to 12 kilometers away from the river.

The old gold placers of Bohemia and Saxony and of some adjoining countries are described in F. Posepny's detailed monograph[2].

In Saxony the most important instance is that of the alluvial masses of Göltsch river in the Vogtland, which of late have induced attempts at washing. The collections of the Freiberg mining academy possess placer gold from that river.

Gold was formerly washed in upper Italy, in the valleys of the Dora Baltea, Sesia, Soanna and other Alpine rivers; in Spain on Rio Sil and Rio Duerna in Galicia, as well as in the plain of Granada; in France at Bonnac on the central plateau, and elsewhere.

11. *Theories to Explain the Distribution of Gold in Placers and the Formation of Large Nuggets.*

Various explanations have been given of the fact, observed in so many regions, that the placer gold of the gravels, sands and clays has become concentrated mainly in the lowest layers of those deposits, resting directly on the bedrock, and in some instances has even entered into the outcrops of the rock bottom, so that the upper, crumbly layers of the bedrock may be worked for gold, as is done, for example, in the Ural.

Leaving out of account for the moment the occasional occurrence of large nuggets, to be discussed a little later, the concentration of the finely divided gold at the base of the placers *during* their deposition by rivers is very difficult to explain. A natural concentration, a settling process on a large scale, cannot be assumed, as very properly pointed out by F. Posepny[3], for the reason that the material of the placers usually shows no sorting or classification, but on the contrary proves to be composed throughout its thickness of particles often varying greatly in size and weight. In fact,

[1] A. Daubrée: 'Sur la distribution de l'or dans la plaine du Rhin,' *Ann. des. Mines*, 1846, 4th series, Vol. X, p. 1, and 'Description géol. et minéral. du dép. du Bas-Rhin,' 1852, p. 319 *et seq.*

[2] F. Posepny: 'Die Goldvorkommen Böhmens und der Nachbarländer,' *Archiv f. Prak. Geol.*, 1895, Vol. II, pp. 1–499.

[3] F. Posepny: 'Zur Genesis der Metallseifen,' *Oesterr. Zeitschr.* f. B. u. Hüttenw. 1887, Vol. XXXV, p. 325. Also 'Ueber die Genesis der Erzlagerstätten,' 1894, p. 207 *et seq.*

we know from geological observations that the loose débris forming a placer was not moved or even stirred up by the water all at once, but on the contrary was deposited at different periods, layer after layer.

Posepny's explanation (given on page 621) is regarded as more probable. While according to this hypothesis the concentration of the finely divided placer gold on the surface of the bedrock, or of an impervious intermediate layer, is to a certain degree intelligible as a purely mechanical process *after* the deposition proper, the occasional occurrence of large gold nuggets, such as are very rarely found in lodes, presents further difficulties not met by this theory. The largest gold nugget from the Ural was found in 1842 in the Tsarevo Alexandrovsk placer at Miask, directly on the dioritic bedrock, and weighed 36 kilograms (79 lbs.) It is said to have been surrounded by hard clay. The largest Australian nugget, found at Dunolly in Victoria, and called "Welcome Stranger," was almost entirely free from impurities and weighed 70.9 kilograms. The next largest, "Welcome Nugget," found at Ballarat, at a depth of 54 m. (177 ft.) in 1858, contained 67.3 kilograms of gold. It was apparently waterworn and the gold intergrown with quartz and iron oxide.

At first thought a purely mechanical transportation of the gold from the weathered outcrop of gold lodes or older stratified auriferous deposits appears certain. In fact, the occurrence of large nuggets in gold veins, though rare, is yet a well recognized fact. Thus, according to Newberry, in a quartz vein at the Monumental mine, Sierra Buttes, California, a lump weighing 40 kilograms was found. The nuggets found in placers with gravels and vein quartz attached and intergrown show that large masses can be transported from veins into the placers by purely mechanical processes. Proof of this is afforded by the nugget weighing 40 kilograms discovered by a native in 1851 in Meroo creek in Victoria, which according to Liversidge[1] was still coalesced with vein quartz. This nugget was found on the surface of the earth; in fact, gold nuggets seem to occur at all possible horizons and are to be by no means confined to the surface of the bedrock. The apparently much greater rarity of large nuggets in lodes than in placers is in part explained by the fact that a gravel deposit of any considerable thickness corresponds to a much greater section of a lode (whose destruction occupied thousands of years) than man is ever able to become acquainted with during the working of a mine.

Grave doubts of the purely mechanical origin of placer gold are, however, aroused by a comparison of the nuggets of veins with those found in placers. The former invariably represent crystalline aggregates, usually intimately intergrown with quartz, showing many projecting spurs and

[1] Liversidge: 'The Minerals of N. S. Wales,' 2d ed., p. 67.

sheet-like offshoots. Moreover, the gold is low grade, being strongly alloyed with silver. During transportation in water, by the current of a brook or river, and mixed with vast quantities of cobbles and sand grains, pounding and rubbing against the gold and each other, it seems certain that these projections must be rubbed off and the lumps would finally assume a rounded form and smooth surface. In fact, nuggets are often found in placers which bear out these assumptions. We have seen pebble-shaped nuggets from West Australia, and T. Egleston[1] has described some from Venezuela. The West Australian nuggets which were submitted to us for examination by Mr. Gmehling showed a distinct rounding along the periphery at all the projections and edges, while in the re-entrant angles traces of the original jagged structure of vein gold had been preserved. The great majority of the nuggets found in gravels, however, differ from vein gold in the following points:

(1) Their surface is very irregular, covered with warts or nipple-shaped growths, which do not harmonize with a pebble-like character, but rather suggest a concretionary origin.

(2) They are but rarely mixed with quartz, which appears quite inexplicable, especially for the very large nuggets, if they are regarded as mechanically transported vein gold.

(3) Their fineness in most cases is much higher than that of vein gold. According to Posepny the placer gold of the Ural contains 91 to 99%, the vein gold only 86.6%.

As regards (3), it must be admitted that the number of observations made is as yet much too small to be conclusive. Moreover, in making such comparisons, too much stress must not be laid on the fineness as ascertained on a large scale in stamp-mills. The gold obtained from veins is too easily mixed with traces of other metals occurring in such lodes.

These facts led F. A. Genth, O. Lieber, A. R. C. Selwyn, M. Laur and later T. Egleston, C. Newberry, Daintree and others to the hypothesis that the gold of the gravels, especially the nugget gold, was for the most part deposited from solutions which had circulated through the beds of gravel and sand. It is thought that either the fine "dust" introduced mechanically and uniformly distributed through the placers was dissolved and afterwards redeposited in certain layers or about definite centers, or else that gold-bearing solutions, formed during the decomposition and weathering of the lode, were carried to the placer by ground-water currents.

A fourth reason, not very weighty, it is true, is drawn from observations,

[1] T. Egleston: 'The Formation of Gold Nuggets and Placer Deposits,' *Trans.* Am. Inst. Min. Eng., 1881, Vol. IX, p. 633.

which it is difficult to verify, that placer gravels after working become after some time richer again.

The fact that gold-bearing solutions actually do circulate in placers seems proved by the existence of unquestionably newly formed auriferous pyrites in placer gravels. In the Ballarat goldfield H. A. Thompson found crusts of auriferous pyrite around roots and branches of plant remains. Crystallized iron pyrites on a piece of wood in a placer, directly under an overlying basalt sheet at Ballarat, gave 0.12% gold. One specially convincing example is the auriferous character of iron pyrite found in the middle of an old tree-trunk found in a placer of that locality. This pyrite held 46.1 grams of gold per ton[1].

Roots of trees in the gossan of gold veins are also sometimes coated with gold, as shown by the samples from the Great Boulder Main Reef of West Australia, exhibited in Paris in 1900.

When, moreover, small quartz pebbles are seen to be cemented by gold, as is the case with a specimen at Karlsruhe, mentioned by Brauns[2], it is a strong argument for the segregation and deposition of the metal from a solution.

Important evidence, showing that gold passes into solution in the outcrops of primary deposits, and may in this shape be carried to and through placer deposits, has been furnished by the observations of Lungwitz[3] in the goldfields of Omai, in British Guiana. The ashes of trees that had grown on the goldfield contained a slight amount of gold content, the percentage being decidedly greater in the material from the upper part of the trunks close to the branches, and including the stubs of the branches, than in that from the lower part. He infers that the water absorbed by the roots of these trees contained gold. This agrees with observations upon the placers of that locality, which, contrary to the usual rule, are richer in the upper layers than in the lower. The upper layers, not having been exposed so long, are not leached out to the same extent as the older, lying at the base of the placer. Should these statements be corroborated by analogous investigations, they will be of great importance.

That gold occurs in solution in nature outside of veins is shown by its presence in sea-water, as proved by Sonstadt[4]. According to him, sea-water contains 0.06 grams of gold per ton. This is confirmed by the detailed investigations of A. Liversidge. According to him, the sea-water

[1] Phillips-Louis: 'Ore Deposits,' 1896, p. 631.

[2] R. Brauns: 'Chemische Mineralogie,' 1896, p. 406.

[3] E. E. Lungwitz: 'Ueber die regionalen Veränderungen der Goldlagerstätten,' Thesis Rostock, Leipzig, 1899.

[4] *Chemical News*, Vol. XXVI, p. 159. *Amer. Chemist.*, Vol. III, p. 206.

along the coast of Australia contains 130 to 260 tons of gold per cubic mile of ocean, that is to say, 0.03 to 0.06 grams per ton[1].

The solubility of gold in various saline solutions such as occur in nature, in very dilute form, was studied experimentally by T. Egleston (*l. c.*). He found, for example, gold to be soluble in a solution of ammonium nitrate mixed with some ammonium chloride, and also with sodium and potassium sulphates. H. Wurtz had previously demonstrated the solubility of gold in ferrous chloride and in ferric sulphate. At any rate, the facts show that in nature gold may pass into solution, especially during the weathering of gold veins, where sodium chloride, free sulphuric acid and manganese oxide (haussmannite) may occur side by side, so that even free chlorine may be formed. Organic solvents do not appear to be indispensable, as supposed by E. E. Lungwitz.

On the other hand, the precipitation of the gold from solutions within the gravels offers but little difficulty. Egleston proved by numerous experiments that organic compounds, such as occur in river-water and in ground-water, are able to reduce metallic gold from solutions. Thus, for example, bits of peat introduced in gold solutions induced a precipitation of metallic gold. As drift deposits very frequently contain not only pieces of wood, as observed in California and Australia, but also other vegetal detritus, and as, moreover, the gravels are occasionally overlain by a cover of peat, as in the Ural or in Siberia, and as the ground-water traversing those masses of drifts must constantly receive admixtures of organic acids from growing peat bogs, the precipitation of gold from solutions within the placers, or at any rate a growth of gold around grains or nuggets of mechanical introduction, is certainly, to say the least, well within the range of possibility.

According to H. A. Gordon[2], a notable precipitation of gold in alluvium requires special conditions not everywhere present, such as aridity and hot climate, which prevent the gold solutions furnished by nature from being washed down into the sea and enable them to be concentrated. Such conditions prevail, for example, in Queensland and West Australia and in New Zealand in the dry Otago region. In the latter region, especially in the Upper Tairi district, considerable quantities of "wire gold" were occasionally found, always on the surface of the ground or directly under it. The earlier prospectors looked upon it as roots of grass fossilized into gold. McKay saw a sample of it at Naseby in 1881, weighing 1.2 kilograms. It consisted of thin, straight or bent wire. One side was smooth or striated,

[1] A. Liversidge: 'Gold and Silver in Sea-water,' *Journ.* of the Royal Society of N. S. Wales, 1895, Vol. XXIX.

[2] 'Hysteromorphous Deposits (etc.) in New Zealand,' *Trans.* Am. Inst. Min. Eng., 1896, Vol. XXV, p. 292.

the other was covered with small, cubical gold crystals. There seemed to be no possibility that these finds might be derived from denuded lodes.

As the matter now stands, the view expressed by Cohen[1] in 1887, after a critical discussion of all the works then in existence on this subject and subsequently supported by Posepny[2], is still valid, "that by far the larger part of the detrital gold became liberated by the mechanical destruction of older deposits and was mechanically deposited, but that on the other hand a segregation from solutions undoubtedly occurs, though it plays but a subordinate part."

(e) Platinum Placers.

1. *Platinum Placers in the Ural*[3].

The most important platinum-bearing placer deposits of the Ural are those of Goroblagodat, Nizhne Tagilsk and Bisersk. The placers are situated mainly in the basins of the Iss and Tagil rivers, tributaries of the Tura, in the basin of the Vyja.

In the Tagil region, the platinum deposits occur about Mount Soloviov, in the valleys of the Chaush, which runs northward from that mountain stock, that of the Vyssym running west, and that of the Martyan running south. Mount Soloviov consists of peridotite, while the adjoining rocks to the east consist of gabbro-diorite and diorite. The olivine rock passes into olivine gabbro and into various diallage rocks, and has in many cases been altered to serpentine. That all these olivine-bearing rocks are the mother rocks of the platinum (see page 15) is proved by ore-dressing experiments that have been made on a large scale. Per contra, Saytzeff states that, while the peridotite is the chief source of the platinum, the metal is also present in the syenite. This statement is surprising and needs confirmation, but is in accord with recent observations of Kemp and of Brock in British Columbia. It should be observed that not all the peridotite masses of the Ural contain platinum. A very good review of the occurrence of the Ural platinum deposits, with a full list of recent publications, is given by Purington[4].

[1] E. Cohen: 'Ueber die Entstehung des Seifengoldes,' *Mittheil.* des naturw. Vereins f. Neuvorpommern u. Rügen, 1887, Vol. XIX.

[2] F. Posepny: 'Genesis der Erzlagerstätten,' 1894, p. 203.

[3] Bourdakoff and Hendrikoff: 'Description de l'exploitation de platine,' translated from the Russian by G. O. Clerc. Ekaterinburg, 1896. A. Saytzeff: 'Die Platinlagerstätten am Ural' (in Russian). Tomsk, 1898. C. W. Purington: 'Platinum deposits of the river Tura,' *Trans.* Am. Inst. Min. Eng., February, 1899, Vol. XXVII, p. 440. J. F. Kemp: 'The Geolog. Relations and Distributions of Platinum and Associated Metals,' *Bull.* No. 193, U. S. Geol. Survey, 1902, p. 95, with full bibliography.

[4] *The Engineering and Mining Journal*, May 5, 1904, p. 720.

Both the size and the form of the platinum found in the placers changes downstream. Farthest upstream the metal occurs in small nuggets, often angular and rough, and not infrequently coated with a film of ferric hydrate ("platinum in the cap"). It is only in this head-water area that nuggets have been found, the largest one known weighing nearly 10 kilograms (22 lbs.). Farther downstream, the platinum occurs in rounded or flat grains with smooth surface. Some of the grains are found still intergrown with chromite, the companion mineral of platinum in the peridotite and other olivine rocks.

Placer platinum is always impure, and the chemical composition varies for each locality. It contains 51.5% to 86.5% of platinum, with 5% to 13% of iron, and some gold, iridium, rhodium, palladium, osmium and copper. The following analyses of placer platinum from the Ural and from three localities in North America are after Deville and Débray[1] (I-III) and G. C. Hoffmann (IV)[2]:

	I. Ural.	II. California.	III. Oregon.	IV. British Columbia.
Platinum	76.40	85.50	51.45	72.07
Gold	0.40	0.80	0.85	.....
Iron	11.70	6.75	4.30	8.59
Iridium	4.30	1.05	0.40	1.14
Rhodium	0.30	1.00	0.65	2.57
Palladium	1.40	0.60	0.15	0.19
Copper	4.10	1.40	2.15	3.39
Irodosmine	0.50	1.10	37.30	10.51
Sand (chromite, etc.)	1.40	2.95	3.00	1.69
	100.50	101.15	100.25	100.15

Besides the platinum and the chromite already mentioned, the platinum placers of the Ural contain some iridium, irodosmine and usually also gold.

The platinum in the placers is concentrated on the bedrock, especially where that surface is rough, a corroded limestone offering specially favorable substratum for placers. The richest placers are found in expansions of the valleys.

The platinum sands washed in 1892 contained on an average 3.3 grams of platinum per ton. Since then the washing of even poorer sands has been taken in hand.

Part of the placer gravel is of a residual character. Thus in all the innumerable gulleys radiating from Mount Soloviov, the talus fragments which have slipped but a few meters down the slope are gathered and taken down the valley to be washed for platinum.

[1] Deville and Débray: *Ann.* Chim. Phys. (3) 56, p. 449.

[2] Cited by J. F. Kemp, p. 50.

In the true alluvial placers the material varies from coarse to fine, according to the location. The overburden is sometimes so thick that bedrock drifts have to be driven underground. An average section of the platiniferous alluvium in the valley of the Iss, after A. Saytseff, is as follows:

'Turfa' { real turf (peat), whence the designation 'turfa' originated, and sand;
sandy clay;
blue-gray tough clay.

'Ryetchnik,' that is to say, river sand and gravel with large pebbles, without platinum.
Platiniferous sand, 0.7–1.4 m. (2.3–4.6 ft.) thick.
'Potchva,' that is, bedrock.

Sometimes the platiniferous gravel is cemented into a conglomerate. The horizontal distribution of the pay streak varies greatly. Two platiniferous layers have sometimes been found one above the other in the same placer, as in the washings of Alexei-Olginsky, on the Little Osokina.

The platiniferous deposits are in part of Pleistocene age, as proved by tusks and bones of the mammoth in the 'ryetchnik' of the Bokovoi and Yelizavetinsky placers. The Ural placer deposits have been subjected to protracted degradation and represent the remains of vast rock masses destroyed in the course of many thousands of years, during which the minute platinum content of the peridotites was subjected to repeated or continuous concentration, longer than in other regions of the globe.[1]

In the Ural, platinum was first found in 1819 in the gold placers of Dakovlev. Since the discovery of platinum in the district of Nizhne Tagilsk in 1825, up to 1892 a total of 113,211 kilograms of that metal were obtained in the Ural[2]. In 1898 the platinum production of the Ural was 6,027.2 kilograms, in 1901 it was 6,328 kilograms.

2. *Occurrences of Platiniferous Gravels Elsewhere.*

On the Pacific coast of America, sea sands and river gravels, colored black by magnetite and menacconite, contain some platinum, iridium and osmium, together with gold, as in the vicinity of Klamath river in Siskiyou county and in Humboldt and San Francisco counties in northern California and in Oregon. A few hundred grams of platinum ("white gold" of the miners) are obtained every year.

Platinum occurs in commercial quantity, according to Day[3] and Kemp[4] in the placers of the Tulameen river near Princeton, in British Columbia.[5] The nuggets sometimes contain intergrown chromite, olivine and augite.

[1] Kemp: *Op. cit.*

[2] 'The Mineral Industry,' 1894, p. 596.

[3] D. T. Day: 'Notes on the Occurrence of Platinum in North America,' *Trans.* Am. Inst. Min. Eng., Feb. 1900.

[4] *Op. cit.*, p. 47.

[5] R. W. Brock: *The Engineering and Mining Journal*, Vol. 77, p. 280.

The mother rocks of the metal are, according to Kemp, the peridotite, dunite and pyroxenite, which outcrop on the upper course of the river. A slight amount of platinum was discovered along a belt of crushed granite heavily stained with chlorite.

It must be noted that specimens were found which were mechanically intergrown with gold and at the same time had adhering to them remnants of dolomite and magnesite.

Very slight quantities of this metal were obtained from some gold placers of Canada, such as those of Loup river, close to its junction with the Chaudière.

The Colombia, South America, platinum placers are second in importance only to those of the Urals. The platinum comes from the west or Pacific coast area, mainly from the placers of the watershed between the Cauca and Atrato rivers due west of Bogota. The platinum occurs associated with gold, chromite, magnetite and menacconite, nuggets showing it firmly intermingled with gold and chromite. Platinum was first recognized as a new native metal toward the middle of the 18th century in placer gold from Colombian placers, being called platina because of its resemblance to silver (plata).

According to Boussingault[1], platinum has also been obtained from auriferous quartz veins in syenite gneiss at Santa Rosa, in the Colombian province of Antioquia.

Platinum is also known to occur in the gold washings of the Taqui river, on the island of San Domingo.

In New Zealand, platinum has been found associated with gold, osmium and iridium in the gold-bearing placers, though in small amount. It has been found in the beach sands and in river gravels in the southern part of the middle island, notably on the east coast of Otago, on Clutha river and in the Nelson gold district. The Round Hill Gold Mining Company at Orepuki, on Colac bay, obtained up to 1898 about 900 grams of platinum.

Platiniferous sands have also been found in Tasmania.

On the continent of Australia, platinum is known in the gold placers of Fifield and some other points in New South Wales[2]. In 1894 about 31 kilograms (1,093 oz.) of this metal were washed out. Platiniferous sea sands are also found in the same colony on Richmond river.

In Europe platinum occurs, but very scantily, as, for example, in the gold placers of Ollalipian, in Transylvania.

Finally mention may be made of the occurrence of platinum in some

[1] *Ann.* Chem. et Phys. 1826, Vol. XXXII, p. 204.

[2] J. B. Jaquet: 'The Occurrence of Platinum in New South Wales,' *Records* Geol. Survey of N. S. W., 1896, p. 33.

gold placers of Borneo[1]. It is found associated with a good deal of magnetite and blue-gray corundum, as well as with diamond and the exceedingly rare mineral laurite (ruthenium-osmium sulphide). It was first discovered in 1831 in the gravels of Gunung Lawack, southeastern Borneo.

(f) The Copper Placers of the Philippines and Argentina.

According to the verbal statements of F. V. Voit to the author, native copper is found at several points in the basin of the Malaguit, near Paracale, in the province of Camarines Norte, on Luzon. The natives have frequently offered for sale copper sands obtained from the river beds. The copper occurs in fine grains, associated with magnetite, hematite and some gold, the grains varying in size from a millet seed to that of a match-head, and are covered by a brownish-red or blackish crust of oxidic compounds. According to F. Rinne[2], who subsequently examined the locality, the grains for the most part have an irregular prickly surface. Small specimens in the form of threads or cylinders were also observed. With the copper were occasionally found small granules and crystals of iron pyrite, and abundant minute zircons. A very important observation made by F. Rinne is to the effect that, in the brooks at Submaquin and at Calaburnay, many pebbles have a friable crust of cellular-spongy copper, which readily crumbles into copper sand. He justly infers that the native copper of those placers has probably not been transported far, but owes its origin to local processes of reduction of copper solutions by means of organic substances.

True copper placers were described by V. Novarese[3] from Santa Catalina in the northernmost part of Argentina. They consist of unstratified conglomerates of schist and graywacke pebbles, with nodules of oxidic copper ore, which enclose native copper in their center. This deposit, which at the same time is somewhat auriferous, is overlain by non-copper-bearing gold gravels of Pleistocene age.

[1] Th. Posewitz: 'Das Diamantenvorkommen in Borneo,' *Jahrb.* d. k. unga. Landesanst., Vol. VII.

[2] Rinne: 'Kupferreiche Sande im Malaguitgebiet bei Paracale,' *Zeit. f. Prak. Geol.* 1901, p. 387.

[3] Novarese: 'Sui giacimenti auriferi della Puna di Jujuy,' *Rivista* del Serv. Minerar pl 1890.

GENERAL ADVICE TO THE PROSPECTOR.

Those who have read attentively the descriptions herein given of the different types of ore deposits and of the changes which take place in the outcrops of such deposits through weathering, and who have also visited various ore deposits, will hardly need any general directions in prospecting for undiscovered deposits. However, many readers desire a brief summary of the leading facts which a study of ore deposits shows to be of importance to the prospector. The working of discovered deposits belongs to the province of mining and engineering and hence need not be discussed here.

Of all the older so-called prospectors' guides, the brief, simple and concise work of B. von Cotta[1] is still the best, and we shall be able in many instances to follow his clear exposition, excellent especially for its brevity and simplicity. Many good hints are also contained in the recently published work by R. H. Stretch[2].

Such hints are necessarily always of a very general nature. Special rules cannot easily be given, since they would have to be as varied as the geologic nature of the deposits described by us.

It is well known, however, that many ore deposits were discovered by accident, when nobody was looking for them, and furthermore, that most professional prospectors or ore-seekers in unexplored regions of the globe are not geologists, or at most possess only certain elementary and rather instinctive geologic knowledge. Nevertheless, the rude empiricism so successful in this field may still profit by the guidance of certain geologic facts, as will appear from the following considerations.

ASSOCIATION OF ORE DEPOSITS WITH CERTAIN ROCKS.

Von Cotta's leading principle, that "Ore deposits in a general way are found more frequently in regions of older than in those of newer rocks," is still valid. The reason of this, as explained by him, is not that older geologic periods presented more favorable conditions for the formation of

[1] B. v. Cotta: 'Die Lehre von den Erzlagerstätten I,' 2d ed., Freiberg, 1859, pp. 224-236.

[2] R. H. Stretch: 'Prospecting, Locating and Valuing Mines,' New York and London, 1899. C. W. Moore: 'A practical guide for prospectors, explorers and miners,' London, 1893. S. H. Cox: 'Prospecting for minerals,' practical handbook, revised edition, 1900.

ore deposits, but that most of the ore concentrations can take place only in the deeper regions of the globe, under higher temperature and higher pressure than prevail at the surface. This is true not only of all the deposits that have to be regarded as magmatic segregations or as contact-metamorphic formations, but also of most true veins and other epigenetic formations. Only the purely sedimentary ore deposits, and those secondary deposits that were laid down far from the original source of their ores, are exceptions. But all those older parts of the earth's crust that have been subject to those conditions must formerly have borne a heavy cover of younger strata, from which they were exposed only by subsequent erosion. This of course is possible only when they themselves possess a high geologic age.

Usually the country rock of the ore deposits, if not crystalline from the start and thus proof against most plutonic changes, bears traces of the effect of the chief factors concerned in the concentration of ores, namely, high pressure and temperature; that is to say, the rock appears more or less metamorphosed. Thus the metamorphic schists always offer to the ore-seeker a particularly favorable field; he will have to direct his steps toward those regions where those rocks outcrop. It is immaterial whether the crystalline schists belong to the group of Archean schists, admitting of no further determination of age, or whether they have been recognized as metamorphosed Paleozoic sediments.

The possibility of finding ore deposits in such ancient, and especially in such metamorphic, rocks is further increased if certain other conditions prevail. Above all, as a general rule, in regions of geologically ancient sedimentary rocks, those districts are especially favorable which have a mountainous character or had it in former geologic periods, having been more or less planed down by subsequent erosion. This principle is about equivalent to the observation of general geology, that crystalline schists are found mainly in mountainous regions or in degraded tracts that formerly possessed a mountainous character.

The very oldest German writers on mining matters made a distinction among mountains. They preferred "gentle middle mountains and flat valleys" to abrupt, jagged, "piecemeal" mountains of Alpine character, and, on the whole, not without reason. Modern folded mountains—modern in the geologic sense, such as the Swiss Jura, the larger part of the Alps and the Carpathians proper—with their abrupt forms contain on the whole but very scanty ore deposits; on the contrary, the older mountains, especially those whose principal uplifts fall within the Paleozoic period, such as the Erzgebirge and the Hartz, are on the whole much richer in ore deposits, and the same is true of old mountains almost planed down by the

activity of water, veritable ruins of mountains, such as the Rhenish Schiefergebirge. The reason of this phenomenon is, that in the more youthful "folded mountains" the real seats of the ore concentrations, viz., the crystalline cores, are not yet sufficiently freed from their vast cover of younger sediments. As a rule, the only metallic treasures of such geologically modern mountain ranges are ore deposits formed syngenetically with the country rock, especially iron ore deposits. (These remarks apply principally to areas of crystalline schists. The great ore deposits of the western United States and Mexico occur in Tertiary rocks and in regions of rugged peaks and high mountains. W. H. W.)

The limits within which the prospector must chiefly rely upon making valuable discoveries is still more closely defined, and his path more clearly apparent, if he remembers that by far the greatest number of epigenetic and of course all magmatic ore deposits are more or less closely connected with masses of eruptive rock.

Throughout this work especial stress has been laid on the significance of the genetic association of ore deposits with plutonic centers, either as the roots of old volcanoes and great intrusive masses which have been exposed by long and great denudation, or in ancient and modern volcanic masses solidified near the surface. Summarized, this association is as follows:

Granites, especially those that contain tourmaline, lepidolite or topaz, one or all, are exceedingly apt to be associated, all over the globe, with tin veins and impregnations. Granites, more particularly aplites, have also in many cases been regarded as responsible for the formation of gold veins. The silver-lead deposits also are probably in many cases in close genetic relation to granitic rocks, as was again proved recently by the detailed study by Dalmer[1] of the Erzgebirge. Lastly, the contact-metamorphic deposits, so varied in their metallic contents, occur on the borders of granitic, syenitic or dioritic masses. We have seen that gabbros, diorites, peridotites and serpentines are connected with deposits of nickel-copper ore; augite-syenites and non-quartzose porphyries with iron ores; diabases and diorites (in part transformed diabases) with gold ores; other diabases and melaphyres with copper ores; dacites and liparites, especially when altered to propylite, with silver-gold ores, etc. Hence the prospector will have to devote special attention to such eruptive masses.

SPECIAL INDICATIONS OF ORE DEPOSITS.

After the general features of a region have been carefully considered in connection with the generalizations just presented, a search must be made

[1] K. Dalmer: 'Westerzgebirgische Granitmassivzone,' *Zeit. f. Prak. Geol.*, 1890, pp. 287-313.

for special indications of ore deposits. In this search the color of the outcrop is of especial importance. This is shown not only in the outcrop when exposed either naturally or by prospecting trenches, but also in the loose, weathered soil, in which it forms a so-called "tail" (Schweif) or fan, that is, an area with illy defined borders in which the gossan colors the ground. In cultivated regions this coloration may be visible even on tilled soil. From what has been said about the gossan (p. 365) and its exceedingly varied development, it may be inferred that this coloring may be of the most diverse character. Brown-red discolorations are the most common, and are due to the most heterogeneous deposits. Where copper compounds are present, blue and still oftener green tones may be developed; yellowish ones indicate lead, whitish ones zinc.

Attention must also be paid to the surface configuration, which often betrays outcrops. When the ore masses consist mainly of a resistant gangue, such as quartz, the outcrops will weather out in the topography as elevations. Veins are thus apt to be conspicuous as reefs or crests, often persistent for long distances. On the contrary, if the predominant gangues are easily leached out, as in the case of carbonate spars, or the vein filling consists almost exclusively of easily decomposable ores, or, finally, if the outcrop is merely a zone of disintegrated rock, not of a true vein, the outcrops form depressions; in such cases the veins on mountain slopes will often coincide with gullies and gulches, since the water cuts easily into the soft zone of weathered material.

The plant growth may also indicate the presence of ore deposits. Certain plants have long been known to botanists and florists in which the color of the petals and possibly other habits undergo marked changes when certain metallic compounds are added to the soil in which they live. Gardeners, for example, use iron oxide to produce certain color variations in *Hortensia*. There are in Nature certain rare instances of particular plants or varieties that are found only in soils containing certain metals. It is true that the data upon this subject, though often mentioned in literature, is in need of critical examination by competent botanists, but certain associations seem to be thoroughly established.

The best known case is that of the calamine violet (*Viola lutea* Huds., *var. calaminaria* Lej.) found on the calamine outcrops of upper Silesia, Westphalia and Belgium, as well as in Utah.

E. Lidgey[1] mentions the following indicative plants: In the limestone soil above galenite beds, in Michigan, Wisconsin and Illinois, the *Amorpha canescens*, a *Papilionacea*, resembling indigo; in the clayey soil with galenite in Missouri, rhus and sassafras shrubs thrive; in Montana the silvery

[1] *Trans.* Austral. Inst. Min. Eng., 1897, Vol. IV, p. 116.

leaved pink flowering *Eriogonum ovalifolium* is common about silver veins (and elsewhere on granite areas. W. H. W.). Finally, according to S. B. Skertchly[1], in Queensland the *Caryophyllacea polycarpæa spirostylis* is said to be an infallible indication of copper in the soil.

As accumulations of ore are often found along lines of displacement, separating two kinds of rock which may be totally unlike, this difference will often find expression in the vegetation. Thus, according to R. H. Stretch[2], in Arizona one finds a monotonous vegetation of yucca on granite, quartzite and other siliceous soils, while areas of clay slate are covered with ocotilla, and the limestone and the more calcareous eruptive rocks with various species of the cactus family. In California, according to this author, the limits of the gold-bearing gravel beds is shown along the mountain slopes, especially in spring time, by certain white-flowering shrubs, since these water-loving shrubs grow where it oozes out between the gravel and the bedrock, or, at any rate, where it keeps the soil moist. Thus a good observer will be careful to note the floral peculiarities of a region.

The facts just mentioned leads us to the indication afforded by springs. Every well-digger knows that springs are especially apt to emerge where fissures traverse the ground, and thus vein outcrops may be indicated by zones of springs. "Every lode has its own water" is an old miners' saying. Sometimes springs issuing from vein fissures carry metallic salts and deposit iron ocher and other metalliferous, muddy decomposition products, the so-called *guhrs,* which indicate the presence of veins close at hand.

A positive proof of the presence of ore deposits near by is the occurrence of the scattered débris from such deposits, commonly called "float" by the prospector. It is found either mixed in the débris on slopes or in the gravels of brooks and river beds. This float commonly consists mainly of gangue, more rarely of metallic minerals, though traces of the latter are often found in the ore pebbles. Quartz, especially lode quartz, which is generally easily recognizable by its corroded appearance, should be carefully looked for. The characteristic metallic minerals associated with ores will often afford useful information to one who knows the paragenetic conditions of ore deposits. The prospector must follow up the streams carrying vein quartz or other gangue, to and along their head-water branches, until a point is reached where the float is no longer present in the bed, and must look then for the vein on the slopes on both sides, or in the bed of the stream. In a similar way the slopes must be examined until fragments of ore or gangue can no longer be seen. It is then probable that the observer

[1] *Gardeners' Chronicle,* Dec., 1897.

[2] 'Locating, Prospecting and Valuing Mines,' etc., p. 152.

is above or higher up the slope than the vein outcrop, and trenches must be dug accordingly.

In prospecting veins it is a great advantage to one to have some knowledge of the prevailing strike of the veins of a region. The prospector ought therefore to carefully observe and record the strike and dip of all strongly marked, even though barren, fissures, in order to obtain the general direction of strike of the veins. This is easy enough if barren quartz veins occur, as they can usually be traced, and the prospecting trenches must then be made as nearly as possible at right angles to this general strike. If it is not possible to obtain such preliminary knowledge, the trenches must be dug in two directions, at right angles to each other.

On page 52 we have laid stress on the importance of the most accurate knowledge possible of the structural features of a region if one is prospecting for stratified deposits. In this case the trenching should be done at right angles to the general strike of the beds, or as near it as possible.

It is, of course, apparent that in looking for ore deposits one must keep a sharp lookout for evidences of old, even prehistoric excavations, dump heaps or depressions due to the caving in of old workings. Details on this point may be found in various text books on mining engineering.

In prospecting for placer deposits somewhat different observations are necessary.

In hunting for alluvial gold, platinum or cassiterite, the most essential feature of the outfit is a gold pan, or batea, with a horn (miner's horn spoon), which is easily carried and can be used with very little water, and is thus adapted even to arid regions. The prospector must look for and wash the dark-colored, iron-ore-bearing parts of the sand, especially those which have collected in the depressions of the bedrock or between the heavier boulders. These sands are most apt to contain the precious substances sought for, if they occur in the drift. The best places to search are the convex sides of river bends, or points where the brooks enter a widening of the valley. In any case, very many unsuccessful attempts will have to be made, and even when values are found in one sample many others are still needed to attain definite results. The presence of the substances sought for may be betrayed, even before their discovery, by the characteristic associated minerals previously enumerated; chromite will point to platinum, cinnabar to gold, topaz and tourmaline to cassiterite.

Skilled prospectors are able, from the number of gold particles (colors, called also pintas) glistening in the dark-colored heaviest residue in a pan, to estimate the richness of the placer, and in some cases the minute gold particles invisible to the naked eye are gathered by amalgamation in the pan. For this reason, or on this account, the value of gold placers is not

usually given as so much per ton of sand or gravel, but is stated in terms of a definite cubical unit, usually so many dollars or cents per cubic yard, or so much per pan; in California, for example, a cubic yard equals 150 pans, a pan being approximately 25 pounds. When once the auriferous character of a gravel or sand deposit has been recognized, the next task will be to expose its deepest layers, which are usually particularly rich, and in certain cases to obtain an idea of the course and succession of the rich layers (pay streaks). The metal must be looked for in each and every layer, even the uppermost, which is usually decomposed into clay. In making this detailed investigation of a placer, deep test pits will have to be dug or borings made, which should be put down in definite order, usually in rows transverse to the direction of the valley, the results being carefully platted, so that the value and extent of the deposit may be calculated.

A search should afterwards be made for the primary deposits which have supplied the placer. The stream bed above the placer must be carefully examined, and if large and but slightly rolled fragments are found in the stream bed, the search should be conducted with special care, because the deposit may be close at hand.

If the latest formed alluvium is metalliferous, a search should be made for old river terraces, especially elevated gravel and sand deposits of Pleistocene or Tertiary age. These are not infrequently found preserved beneath a protecting cover of basalt. Hence basaltic table mountains or high plateaus, where old river courses are suspected to exist, must be carefully examined. The practiced eye recognizes them from a great distance by their shape. When a country contains placers the sand of its coast may occasionally contain gold or platinum. In testing such sands the blackish particles are most apt to contain the metal.

A special manner of prospecting is used in hunting for deposits of magnetite, and to some extent for those of pyrrhotite. Brilliant success has followed the use of the magnetic compass for the discovery of such deposits, especially since the invention of the Swedish mining compass by D. Tilas in 1672. The method was scientifically elaborated by R. Thalén about 30 years ago, and has been materially improved by E. Tiberg. The description of the Thalén-Tiberg magnetometer and its application may be read in the works cited below.[1] That the usefulness of the method is by

[1] R. Thalén: 'Redogörelse för en ny method att medelst magnetiska mätningar undersöka jernmalmsfält,' etc. Övers. Kongl. Vet. Ak. Förh., 1874, part II, p. 5. See also part IV, p. 7, part VIII, p. 3. E. Tiberg: 'Om magnetiska mätningar vid jernmalmsfält medelst den magnetiska inklinationsvagen,' Jern-Kontorets *Ann.*, 1884, pp. 29-67. H. Lloyd Smyth: 'Magnetic Observations in Geological Mapping,' *Trans.* Am. Inst. Min. Eng., Sept., 1896. G. Nordenström: 'Dans L'Industrie Minière de la Suède en 1897,' Stockholm, 1897, pp. 20-30. Th. Dahlbloom: 'Ueber magnetische Erzlagerstätten und deren Untersuchung durch magnetische Messungen,' translation

no means confined to iron ores in northern regions is proved by its successful application by K. Johansson to the ore field of Marbella, Estepona and El Pedroso in southern Spain, and recently also with specially sensitive instruments by P. Uhlich at the nickel-ore deposit of Sohland, in Lusatia. It has a great future before it, and it may be said that for magnetic iron-ore deposits the divining-rod has been resurrected in scientific form.

THE TAKING OF SAMPLES FOR SCIENTIFIC PURPOSES.

When the prospector has found an ore deposit and has done the first development work he should carefully sample it. The method of doing this is given in books on assaying[1], and hence need not be touched here. Another kind of sampling, however, may well be described here, namely, that which is to furnish the basis for a scientific geologic description of the ore occurrence. This is lamentably unfamiliar even to otherwise well trained miners and explorers. The following rules should, so far as possible, be observed when sampling a deposit for this purpose:

(1) First of all, make a sketch of the occurrence, even though on the crudest topographic basis, denoting on it by figures the points from which the several samples were taken.

(2) The corresponding numbers should be at once attached to the sample by means of labels, or, better yet, painted on with cinnabar color when this is possible. These figures are rendered still more indestructible by a varnish of ordinary shellac. The samples should be accompanied by cards bearing the same numbers, or by a corresponding list.

(3) A cross-section, be it ever so simple, should always be added, and should be inscribed with the corresponding figures.

Next collect:

(4) Samples of the undecomposed ore from the deep portion of the deposit; also of the decomposed outcrop.

(5) Fresh country rock outcropping at some little distance, and perhaps also decomposed country rock immediately adjoining the deposit from both the underlying and the overlying beds, in hand specimens and also in smaller fragments, suitable for chemical or microscopic examination.

(6) The same from eruptive dikes or masses outcropping in the vicinity.

of P. Uhlich, Freiberg, 1899. P. Uhlich: 'Ueber magnetische Erzlagerstätten und deren Untersuchung mittelst des Magnetometers.' *Jahrb.* f. d. Berg- u. Hüttenw., Freiberg, 1899, pp. 1-43, and 'Weitere Beitr. zur. Aufsuchung magnetischer Erzlagerstätten,' same place, 1902, pp. 98-128. Magnetometers can be obtained from Berg of Stockholm or Pässler of Freiberg.

[1] B. Kerl: 'Probirbuch,' third edition, 1894, p. 2 *et seq.*

(7) Fossils from the fossiliferous underlying and overlying strata, when such strata are present.

(8) Samples of clayey, gougy and gravelly masses connected with the deposit, material to which assayers, too, should pay close attention, despite its apparent worthlessness (for instance, the argentiferous gouge of many occurrences).

(9) In the case of placers, both crude and washed or concentrated material, should be packed in sacks, and, when possible, samples of each layer of the cross-section of the placer.

A small but well selected and labeled collection of this kind may be of greater scientific and perhaps also of more practical value than a large collection assembled without method and improperly labeled or packed.

Only when real mining is carried on will it finally be possible completely to satisfy scientific demands and to obtain larger samples, showing, if possible, both the structure of the occurrence and both selvages, together with the country rock.

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